DEVELOPING FORMWORK LABOR PRODUCTIVITY STANDARDS FOR BUILDING CONSTRUCTION IN THE EASTERN PROVINCE OF SAUDI ARABIA

BY

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In

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DEDICATION

This research is dedicated to Almighty Allah, my beloved creator and master, who has been my greatest source of strength in my darkest times. My work is also dedicated to my most beloved person, the Prophet Mohammad. Peace be upon him, the great teacher and messenger who has taught us the purpose of life.

I would also like to dedicate my research to my cherished parents, Nader Al-Nakdali and Raghda Ramdoun. No words can ever describe their precious sacrifice and dedication to illuminating my path and helping me to achieve my goals and dreams. I must also express my heartfelt thanks to my lovely sister and brother, Dania and Rashed, for their endless support and love and for standing by me through the various difficulties of life. I dedicate this work to all of my family members, including my brother-in-law Abdulmalek AL-Amin, and my beautiful niece Sema. I am also deeply and profoundly grateful to my loving grandmothers, Monesa Zidan and Emthal Abo Kaoud. They granted me the love that made me who I am today.

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Humbly, I hope this work contributes to the enrichment of knowledge and increases the prosperity of humankind.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

“US	:	United States”
“GDP	:	Gross Domestic Product”
“TFP	:	Total Factor Productivity”
“PFP	:	Partial Factor Productivity”
“ANN	:	Artificial Neural Network”
“SNI	:	Indonesian National Standard”
“CPMS	:	Construction Productivity Metrices System”
“TMIBLP	:	Theoretical Model for International Benchmarking of Labor Productivity”
“DI	:	Distribution Index”
“PR	:	Performance Ratio”
“PMI	:	Project Management Index”
“IQR	:	Interquartile Range”
“CWH	:	Crew Working Hour”
“SLWH	:	Skilled Labor Working Hour”
“TRFW	:	Time Required to Finish the Work”

“DWH	:	Daily Working Hours”
“TWH	:	Total Working Hours”

ABSTRACT

Full Name	:	DEYA ALDEEN NADER ALNAKDALI
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Despite various technological advances, construction is still a labor-intensive industry and labor productivity is the major determining factor of performance. The construction industry in Saudi Arabia is facing low labor productivity rates, which is having a negative impact on the economy. Moreover, when we track the historical records of construction projects, we found that most public and private projects suffered from cost and time overruns. There is a lack of research exploring labor productivity ratios in Saudi Arabia, in which industry experts measure the efficiency of the workforce and establish reasonable benchmarks. Thus, the present work develops a rigorous approach to determining productivity rates for labor productivity related to formwork activities for major building elements under normal operating conditions in the Eastern Province of Saudi Arabia. Data were collected from 31 reinforced concrete building construction projects, including villas and other residential structures with a maximum of five floors, located in the largest cities of the Eastern Province (i.e., Dammam, Khobar, and Dhahran). These included both public and private sector projects. Data were collected from contractors' historical records and direct measurements from the construction sites of ongoing projects. A box plot analysis was used to statically analyze the data, presenting summary numbers for each dataset. The median and inter-quartile range represented the performance standard rate and normal labor productivity range of

the related activity, respectively. An explanation of the methods used by local contractors to determine their performance range is also provided. Although the measurements are specific to Saudi Arabia, this methodology can be used in other countries to collect and analyze this type of data.

ARABIC ABSTRACT

ملخص الرسالة

الاسم الكامل: ضياء الدين نادر النكدلي

عنوان الرسالة: تطوير معايير إنتاجية العمال لأعمال الشدات الخشبية في مشاريع البناء في المنطقة الشرقية في المملكة العربية السعودية

التخصص: ماجستير العلوم في هندسة وإدارة التشييد

تاريخ الدرجة العلمية: جمادى الأولى ١٤٤٢

على الرغم من التطورات التكنولوجية المختلفة، لا تزال صناعة البناء تعتمد على العامل البشري وإنتاجية العمال هي العامل الرئيسي المحدد لأداء هذه الصناعة، ففي المملكة العربية السعودية تواجه هذه الصناعة معدلات منخفضة من الإنتاجية للعمال التي تؤثر على الاقتصاد بشكل سلبي. بالإضافة إلى ذلك، عندما نتتبع السجلات التاريخية للمشاريع الإنشائية نجد أن معظم هذه المشاريع قد عانت من زيادات في الوقت والتكلفة عن المخطط لهما. بينما هنالك نقص في الأبحاث التي تحاول استكشاف معدلات الإنتاجية في المملكة العربية السعودية والتي من خلالها يستطيع خبراء الصناعة قياس مدى كفاءة القوة العاملة وإنشاء معايير إنتاجية ملموسة. ولذلك فإن البحث الحالي يطرح نهجاً فعالاً لتحديد معدلات إنتاجية العمال لأعمال الشدات الخشبية في الظروف الطبيعية للعناصر الإنشائية الأساسية للمباني في المنطقة الشرقية للملكة العربية السعودية. حيث تم التجميع البيانات من 31 مشروع إنشائي لمباني الخرسانة المسلحة والتي تتضمن فلل ومباني سكنية لا تتجاوز خمسة أدوار في المدن الكبرى للمنطقة الشرقية (الدمام، الخبر، الظهران) وتتضمن هذه المشاريع كلا من المشاريع الحكومية والخاصة. تم تجميع البيانات من السجلات التاريخية للمقاولين بالإضافة إلى القياسات المأخوذة مباشرة من مواقع المشاريع خلال الإنشاء. لقد تم استخدام مخطط الصندوق لتحليل البيانات إحصائياً لتحديد الأرقام الخمسة الأساسية الخاصة بهذه الطريقة لكل مجموعة من البيانات في هذه الدراسة. وبناء على ذلك، تم اعتبار قيمة الوسيط كمعدل إنتاجية العمال الخاص بالعمل والمدى الربيعي كمجال الإنتاجية الطبيعية للعمل المحدد. بالإضافة إلى ذلك، تم عرض للطرق المستخدمة عند المقاولين المحليين لحساب معدلات إنتاجيتهم لهذا النوع من الأعمال. وبالرغم من أن هذه المعدلات خاصة بالمملكة العربية السعودية، يمكن استخدام نفس النهج لجمع وتحليل هذه النوع من البيانات

CHAPTER ONE

INTRODUCTION

1.1 Overview

In most countries around the world, the construction industry is a major contributor to the economy. On average, it employs 7% of the world's workforce and contributes approximately 9% to the gross domestic product (GDP) of developed countries (Horta, Camanho, Johnes , & Johnes, 2013) .That percentage is even higher in developing countries. In Saudi Arabia, the construction industry is the second largest commercial sector, after oil and gas (Shash & Alsagoub, 2014). Moreover, Saudi Arabia leads the Gulf's construction industry. The Kingdom plans to spend US$1.1 trillion on infrastructure projects alone in the next 20 years (Linesight, 2020), part of an effort to achieve the goals of the 2030 Vision for Saudi Arabia announced in 2016 by Crown Prince Mohammad bin Salman. A sizeable number of construction projects in Saudi Arabia involve building construction. The Saudi government is currently focusing on increasing the tourism sector to diversify the national income of the kingdom, which has depended on the oil and gas industry for decades. Many published reports have indicated that there is a highly demand for commercial building construction projects such as office buildings, sports complexes (such as athletics fields, golf courses, and parks), shopping centers, and hotels.

Housing construction is another category of large-scale project, with the goal of producing housing units for current and future generations. This is the main goal of the housing program portion of Vision 2030. "The Housing Vision Realization Program aims to provide housing solutions that enable Saudi families to own, and benefit from owning, suitable houses based on their personal requirements and financial capabilities, and improve housing conditions for current and future generations through the provision of suitable and guaranteed financing solutions, adjacent to increasing the supply of housing units at reasonable prices within a fast time frame; implementing programs specializing in securing housing for the underprivileged segment of the society; developing and improving the legislative and operating environment for the housing sector; and maximizing the sector's impact on the overall economy, enhancing its attractiveness to the private sector and developing the local content, leading to job creation and further strengthening of the Kingdom's economy" (Saudi Vision 2030, 2016). For instance, the Ministry of Housing in Saudi Arabia announced that there were 31 ongoing residential construction projects across the kingdom, of which 11 are located in the Eastern Province. In total, these will deliver 12,480 residential units (i.e., villas/residential buildings). These numbers do not include private construction projects such as real estate development and individual housing.

Despite various technological advances, the construction industry remains labor-intensive, and labor productivity is a major factor determining the industry performance. Many researchers have investigated labor productivity, including its short-term effects on construction projects and long-term effects on the national economy. For example, "A 10% rise in construction labor productivity would yield annual savings of about £1 billion to the British economy" (Horner, Talhouni, & Thomas, 1989); the outcomes are similar in many countries. The concept of productivity is discussed later in this research, but based on our understanding of the literature, labor productivity can generally be defined as the ratio of the output to the input, with both expressed as dollars. For each field in each industry, this can change according to the connection between the output and input. In construction, labor productivity is evaluated from two perspectives. The first is the ratio of the physical output measured (for example, as square or cubic meters or tons of steel) to the input, which is expressed in dollars (input can include all the costs required to perform the work, such as equipment, material, labor costs, overhead costs, etc.). In other words, it is the ratio between the earned and estimated work. This definition is used by top management when estimating pricing and monitoring for projects.

The second perspective is focused on labor; it is the ratio of the physical output (such as square or cubic meters or tons of steel) to the input (which is expressed in man-hours). This perspective is widely used by project engineers and managers to monitor the progress of a project with respect to time, which is related to cost. The construction industry in Saudi Arabia is facing low labor productivity rates, with a consequent negative impact on the economy (Shash & Alsagoub, 2014). In addition, most public and private projects still suffer significant cost and time overruns. There is a lack of research on labor productivity ratios in Saudi Arabia, which industry experts could use to measure the efficiency of the workforce, help foreign construction companies estimate cost and time for bidding purposes, and assist local contractors with comparing their performance to that of the market. Most use historical records for project pricing and monitoring.

Reinforced concrete is the most frequently used material in construction projects in both the public and private sectors in Saudi Arabia. Structures ranging from single-family homes to high-rise buildings are designed and constructed using reinforced concrete. The primary reason is the low cost as compared to other materials. The majority of building construction projects in Saudi Arabia consist of three essential construction elements: foundations, columns, and slabs. The use of reinforced concrete is most prominent in three labor intensive trades: formwork, rebar installation, and pouring concrete (Jarkas & Horner, 2015). Formwork is very important. "The cost of formwork is one-third to two-thirds of the overall costs of the reinforced concrete frame" (McTague & Jergeas, 2002). Thus, it is essential to have a good understanding of the activity and factors affecting productivity rates. As Saudi Arabia has harsh weather (the temperature often reaches approximately 50ºC, as in other Gulf countries), there is a lack of research exploring formwork labor productivity ratios that could be used to investigate productivity within and across construction projects.

1.2 Problem Statement

For construction companies, it is essential to be competitive in the market to assure continuity and increase market share. Some struggle with attaining this goal, and by searching in the historical record of Saudi construction firms we found that every few years, big contractors declare bankruptcy and new contractors emerge to control their share of the market. This is the nature of the industry. However, many researchers have concluded that what can ensure continuity is applying the appropriate management tools to make sure projects are successfully delivered within the estimated time and cost. For instance, it is essential to have accurate productivity rates for each activity in a construction project so that accurate estimations can be made. The Saudi construction industry is facing a very serious problem. There is a lack of formal published standardized productivity rates for most construction activities. This is especially true for formwork tasks, which can comprise up to two-thirds the cost of reinforced concrete. There is little information about how contractors determine workforce and market productivity rates, information essential to a strong performance and proper implementation of the tools necessary to increase labor productivity. As a result, three important questions are pursued in the present research. 1) What are the productivity standards for formwork activities related to foundations, columns, and slabs? 2) How do contractors value these productivity standards? 3) What productivity standards, if any, do contractors in Saudi Arabia apply? By answering these questions, we will initiate the process of determining productivity rates for the construction industry in Saudi Arabia, massively improving outcomes and facilitating the identification of new managerial tools that will help construction companies improve their performance, both locally and internationally.

In summary, Saudi Arabia's construction industry faces a very serious problem, the lack of formal published standardized productivity rates for key construction activities. There are no known methods or procedures for contractors in Saudi Arabia to follow when identifying productivity rates. This is a very serious problem in the construction industry that needs to be solved.

1.3 Objective of the Study

This study identifies current practices for developing internal standards for contractors to use, as well as formwork labor productivity rates in the Eastern Province of Saudi Arabia, the largest province in the country and most substantial oil and gas industry in the world.

1.4 Significance of the Study

The significance of this study is that it represents a starting point in the process of establishing official productivity standards for construction activities across Saudi Arabia. This research will serve as a useful reference for future work investigating productivity standards for formwork activities. Another important aspect of this study is that it provides productivity standards for formwork activities in the Eastern Province of Saudi Arabia, which industry experts can use for estimation and monitoring purposes.

1.5 Scope and Limitations

The scope of this study is limited to concrete formwork labor productivity ratios (these materials are widely used in the Saudi construction industry) for the following construction elements: foundations, columns, and slabs. This study will concentrate on two types of foundations: isolated and strip. For columns, this research will address those that are rectangular or square. For slabs, this study will consider only beam-supported slabs.

One constraint on this study is that it only includes building construction projects (residential construction, including villas and residential structures with a maximum of five stories/floors). Also, all projects were located in in Dammam, Khobar, or Dharan, the three largest cities in the Eastern Province.

Another limitation that this study is limited to concrete formwork (timber & plywood) labor productivity ratios for the following construction elements: foundations, columns, and slabs. Additionally, this research is not taking into confederation the complexity of work so this may consider as one of the limitations of this research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Productivity Theory

The first use of the word "productivity" was in an article by Quesnay in 1776 (Vaggi, 1987). In 1883, productivity was defined by Litter as the "faculty to produce" meaning the ability to produce. Less than a century later, in 1950, the Organization for European Economic Cooperation presented an official definition of productivity: "a quotient obtained by dividing output by one of the production factors" (Sumanth, 1984). The US Department of Commerce defines productivity as "dollars of output per person-hour of labor input" (Adrian, 1987). (Peles, 1987) explained productivity as "the performance accomplished by operatives," while (Handa & Abdalla, 1989) described productivity as "the ratio of outputs of goods and/or services to inputs of basic resources, e.g., labor, capital, technology, materials and energy." Another definition of productivity is "the quantity of work produced per man-hour, equipment-hour or crew-hour" (Finke, 1998). The American Association of Cost Engineers described productivity as a "relative measure of labor efficiency, either good or bad, when compared to an established base or norm" (Allmon, Haas, Borcherding, & Goodrum, 2000). (Arditi & Mochtar, 2000), however, described productivity as "the ratio between total outputs expressed in dollars and total inputs expressed in dollars..." Finally, (Horner & Duff, 2001) described productivity as "how much is produced per unit input."

Based on these previous definitions, it is clear that researchers agree that productivity is the ratio of output to input. Thus, two measures of construction productivity have emerged: (1) total factor productivity (TFP), where outputs and all inputs are considered; and (2) partial factor productivity (PFP), where outputs and a single or selected set of inputs are considered (Talhouni, 1990). According to (Jarkas & Horner, 2015), TFP is defined as the ratio of outputs to the sum of all inputs, as shown in Equation 2.1.

$$\mathrm{T}FP = \frac{total\ outputs}{\sum of\ all\ inputs}$$

Equation 1: Total Factor Productivity

Input resources may include (but are not limited to) labor, energy, plants, capital, and materials. TFP is an inclusive measure that accounts for outputs and all inputs, whether tangible or intangible, while PFP presents the relationship between outputs and a single or selected set of inputs. This is demonstrated by the term "labor productivity," where only the input of labor is measured. Other single or PFP measures include capital productivity and equipment. Therefore, PFP can be defined as shown in Equations 2, 3, and 4 (Jarkas & Horner, 2015).

$$\boldsymbol{Labor\ productivity\ = \frac{Output\ quantity}{Man - hours}}$$

Equation 2: Labor Productivity

$$\boldsymbol{Capital\ productivity = \frac{Profit}{Invested\ capital}}$$

Equation 3: Capital Productivity

$$\boldsymbol{Equipment\ or\ plant\ productivity\ = \frac{Output\ quantity}{Equipment\ or\ plant\ hours}}$$

Equation 4: Equipment or Plant Productivity

However, many studies have investigated labor productivity and the factors affecting it worldwide in an effort to advance it and provide methods and tools for its measurement, monitoring, and improvement. To enhance the present research, the extant literature has been examined and is discussed below.

2.2 Labor Productivity

Labor productivity has been investigated by researchers for decades. Many have analyzed the issue as it applies to the construction industry worldwide in an effort to overcome many of the general difficulties with ensuring high productivity, but there is still much room for improvement. This section provides a foundation for understanding previous research efforts with regards to construction labor productivity.

(Golnaraghi, Zangenehmadar, Moselhi, & Alkass, 2019) used various artificial neural network (ANN) techniques, including general regression, backpropagation, and radial base function neural networks and adaptive neuro-fuzzy inference systems to model expected productivity, taking into consideration environmental and operational variables. Each technique was compared to find the best for estimating expected productivity. The authors tested the techniques against datasets of two high-rise formwork operations, concluding that backpropagation neural networks were the most reliable for modeling construction productivity.

(Hidayat & Iskandar, 2019) provided a case study and analyzed labor productivity related to reinforced concrete for office building construction in the Bontang Kuala district of Bontang City in Indonesia, and compared the results to the Indonesian National Standard (SNI, 2002). The authors also described factors influencing labor productivity. The results showed that the actual labor productivity obtained from the site was 28% higher than the Indonesian National Standard, meaning that the standards can be used in estimation. Also, they found that motivation factors, skills, discipline, education, experience, wages/salary, and age all had simultaneous effects on labor productivity as related to reinforced concrete; experience was the most dominant factor.

(Dixit, Mandal, Thanikal, & Saurabh, 2019) summarized studies examining the construction industry, providing a literature review of research published between 2006 and 2017. A total of 101 studies were selected from eight journals. The authors concluded that the main focus of most was labor productivity as it relates to losses in the construction industry.

(Damanhouri & Divya , 2017) conducted an empirical study that determined the physical and job performance factors affecting labor productivity in non-oil industries in Jeddah, Saudi Arabia. The authors applied a descriptive analytical method using a survey of 352 staff workers in the production areas of the examined industries. The results showed that the application of physical factors was first, followed by job performance aspects. The study also showed that some factors affected labor productivity positively, while others were found to affect it negatively. Finally, the authors suggested a model and made recommendations for improving labor productivity in non-oil industries in Saudi Arabia.

(Kazaz, Ulubeyli, Acikara, & Er, 2016) found that most studies investigated factors affecting labor productivity, categorizing such factors and ranking them according to their significance level. The authors ignored both the standard deviation of the factors in one group and the mean values of each group. Managers' viewpoints were generally considered, while evaluations from craft workers were not. Then, they re-evaluated all factors in the same group, according to the craft workers' point of view. The authors identified 37 factors affecting labor productivity and classified them into four groups: organizational, economic, physical, and socio-physiological. They applied a questionnaire and used a relative importance index technique to analyze the resulting data. The results showed that the factor ratings remained the same, but their significance levels changed.

(Shash & Alsagoub, 2014) investigated the factors influencing labor productivity in the Eastern Province of Saudi Arabia. From their literature review, they identified 44 factors affecting labor productivity and developed a questionnaire to collect the necessary data for analysis. A total of 212 surveys were hand-delivered to random contractors in the Eastern Province. Twenty-nine contractors completed the questionnaire; the results indicated that little supervision, lack of incentives, low skill, and unclear technical requirements were the most severe factors affecting labor productivity in the Eastern Province of Saudi Arabia. The authors concluded that researchers from different countries came to similar conclusions, but with different levels of severity.

(Ulubeyli, Kazaz, & Er, 2014) investigated labor productivity in Turkey, describing it as man-hour value and comparing it with the labor productivity rates published by the Turkish Ministry of Public Works. The authors concentrated on two work activities related to construction: formwork erection and repair of reinforcements. The data were obtained through a questionnaire distributed to chief executive officers, site/project managers, and planning engineers working at 82 contracting firms in Turkey. The authors evaluated the results by a sample *t*-test, which indicated that on-field productivity rates (i.e., practical rates) were much higher than those published by the ministry (i.e., theoretical rates), up to four times greater or more. Finally, the researchers determined the reasons behind these differences and how official published productivity rates in Turkey should be updated.

(Nasirzadeh & Nojedehi, 2013) developed a system dynamics-based approach model to simulate labor productivity, considering a variety of different factors. The qualitative model was constructed using "cause and effect" feedback loops. Then, the relationships that existed among several factors were defined and a mathematical model of labor productivity developed. The researchers concluded that using their proposed model, project managers could find the root causes of decreases in productivity and take corrective action.

(Jarkas & Bitar, 2012) studied factors influencing labor productivity in Kuwait, identifying and classifying 45 factors into four groups: management, technological, human/labor, and external. A good sample size of contractors responded to a survey, ranking various factors' effects on labor productivity in Kuwait. The results showed that the top 10 factors were: clarity of technical specifications, the extent of variations in change orders during execution, coordination level among design disciplines, lack of labor supervision, proportion of work subcontracted, design complexity level, lack of inactive schemes, lack of construction manager leadership, stringent inspections by engineers, and delays in responding to requests for information.

(Durdyev & Mbachu, 2011) identified key constraints on onsite labor productivity and improvement measures. The authors interviewed project managers, contractors, and subcontractors in New Zealand, studying their perspectives and other qualitative data collected using a questionnaire. The results showed that the major external constraints on onsite labor productivity were legal compliance, unexpected events, and wider external dynamics (in order of decreasing impact). Internal constraints were found to have a much greater impact on labor productivity than did external factors. In order of decreasing impact, internal constraints identified included rework, level of skill and experience of laborers, suitability of construction methods, buildability issues, and inadequate supervision and coordination.

(Oral & Oral, 2010) developed a self-organizing maps-based algorithm to establish 2D maps, investigate the links among several factors and team productivity, and forecast productivity in particular circumstances. They validated the model using a synthetic data group and data from 101 reinforcement, 144 concrete pouring, and 101 formwork teams. The tests showed that the maps produced by the model were appropriate for gathering data, and the predictive power of the model was better than that of other similar ANN models.

(Dai, Goodrum, Maloney, & Srinivasan, 2009) investigated latent factors affecting the productivity of craft workers. A total of 83 factors were identified through focus groups of laborers and their direct supervisors for nine different construction projects throughout the US. A total of 1,996 surveys were distributed to measure the effects of these factors on construction labor productivity. The top five latent factors identified via analysis of the data provided by the surveys were in decreasing order: tools and consumables, direction and coordination, management of engineering drawings, construction equipment, and materials. The authors also concluded that project management, construction equipment, and craft worker skill level substantially positively impacted labor productivity.

(Song & AbouRizk, 2008) provided a model for measuring and estimating the labor productivity of steel drafting and fabrication workers, gathering historical data from different complete or ongoing projects at that time. First, a measurement system was identified for steel drafting and fabrication productivity. Then, the authors developed a data collection system to gather data and develop an ANN model and discrete event simulation. Finally, they validated the proposed model and simulation by collecting data from a company specializing in steel fabrication. The authors concluded that the ANN model effectively modeled individual activities with complicated mapping relationships between productivity and influential factors and complex, detailed operations. They successfully applied the combination of ANN model and simulation to predict the productivity of a production system involving interconnected activities.

(Park, Thomas, & Tucker, 2005) established the Construction Productivity Metrices System (CPMS), which is a "standard construction productivity data collection tool and provides a framework to report industry norms to benchmark construction productivity." The CPMS contains a list of direct and indirect accounts and 65 data elements grouped into seven major categories. Seventy-three experienced industry professionals were asked to define measurement elements and their corresponding definitions. Initial findings from 16 industrial projects showed that it was possible to produce productivity metrices significant to construction productivity benchmarking, but because the sample size was not large enough, the authors couldn't reach more than general preliminary conclusions.

(Arditi & Mochtar, 2000) presented a continuation of previous research conducted as a long-term study. Surveys were distributed to the top 400 US contractors in 1979 and 1983 to determine potential areas of improvement for labor productivity in the construction industry. This study modified the original survey to be suitable for economic and industrial trends and to overcome the time gap between surveys, which was more than 14 years. The results showed that "cost control, scheduling, design practices, labor training, and quality control" were areas where labor productivity could be improved. The authors found that "prefabrication, new materials, value engineering, specification, labor availability, labor training, and quality control" needed more improvement as compared to what was found with the 1979 and 1983 surveys; field inspection and labor contract agreement were found to need less improvement. The authors also determined that over the years, most respondents took part in activities associated with improving labor productivity, but were not interested in financing such actions.

2.3 Formwork Labor Productivity

Formwork activities are very important and labor-intensive, so it is essential to estimate, monitor, and track formwork labor productivity. In addition, the complexity and outdoor nature of forming concrete shapes mean that many factors can affect labor production; consequently, many researchers have focused on formwork labor productivity. In this section, we will describe some of their work.

(Mine, Wai, & Kang, 2015) conducted an observational study of 15 projects, measuring man-hours spent on formwork. The research was based on statistical analyses of data such as work process and working hours. The authors identified problems inherent in the work itself and the essential aspects of management. The outcome of this study was a methodology for predicting man-hours and unit requirements related to formwork construction at project sites, taking into account dependent variables significantly influencing man-hours, as such as constructed floor area, story height, formwork quantity (FQ), cycle time, average age of workers, and worker experience.

Abdulaziz M. Jarkas has conducted a number of studies of the construction industry in Kuwait, investigating buildability factors affecting formwork labor productivity for different structural elements. His research is an excellent source of information for those seeking to establish a good understanding of how buildability factors affect formwork activity. In his research (Jarkas, Buildabitlity factors influencing formwork labour productivity of isolated foundations, 2010) explored the effects and relative impacts of grid patterns, variability in foundation size, total surface area, and average surface area on formwork labor productivity related to isolated foundations in Kuwait. The author collected a sufficiently large volume of productivity data to analyze using a linear regression method. The results showed a substantial impact of buildability factors on formwork labor productivity and demonstrated the significance of applying the rationalization and standardization principles to the design phase of construction projects.

A related study (Jarkas, Buildability Factors Influencing Micro-Level Formwork Labour Productivity of Slab Panels in Building floors, 2010) also examined the interaction between buildability factors in the design stage and formwork labor productivity for beam-slab floor structures. The labor-intensive process was found to require more labor input than does beamless slabs. The author determined that the main buildability factors affecting formwork labor productivity of building floor slab panels were repetition, the geometry of the panels, and panel area. The results showed the substantial effect of these factors and explained the significance of applying the concepts of design rationalization, standardization, and repetition to the design phase of construction projects.

In (Jarkas, The impacts of buildability factors on formwork labour productivity of columns, 2010) he studied the buildability factors most critical to the structure of a building, with a higher labor unit cost than other structural elements. Because of the complicated nature of forming these elements, particularly non-rectangular structures, production volume is comparatively low. A substantial body of data was gathered and analyzed using a categorical regression technique. The findings showed that the geometry of columns, total and average shutter size, and repetition had the greatest impact on column-related formwork labor productivity.

In a similar study (Jarkas, Buildability factors affecting formwork labour productivity of building floors, 2010) found that beam size variability, the intersection of beams, floor area, average slab panel area, replication of floor layout, proportion of curved beams, beam-to-floor-area ratio, and nonrectangular slab panels had significant effects on formwork labor productivity related to building floors. As a continuation of his research on buildability factors influencing formwork labor productivity, his research (Jarkas, Analysis and Measurement of Buildability Factors Affecting Edge Formwork Labour Productivity, 2010) found that the slab's geometric factors, depth of the slab being edge-formed, and type of formwork material had significant effects on edge formwork labor productivity.

(Moselhi & Khan, 2009) conducted a field study to determine the effects of different parameters on formwork labor productivity in Montreal, Canada. These parameters included weather factors (i.e., temperature, humidity, wind speed, and precipitation), crew factors (i.e., group size and labor percentage) and project factors (i.e., work type, floor level/height, and work method). The data were gathered over a period of 10 months from two construction project sites in Montreal. A neural network model was applied to examine the impact of the previously listed factors on daily formwork labor productivity. The findings showed that temperature had the most considerable influence on formwork labor productivity, followed by height and type of work.

2.4 Benchmarking and Methods for Developing Productivity Rates

Benchmarking has been an interesting research area in the last two decades, not only for its application in lean construction, but also because of the need for measurements and evaluation tools related to labor productivity. Researchers have used a variety of terms to describe the concept. Costa, Formoso, Kagioglou, Alarcón, and Caldas (2006) identified benchmarking as follows: "a systematic procedure for measuring, documenting, and comparing the productivity of an entity in one level of the construction context against that of other entities in the same level." Another definition was provided by (Abdel-Razek, Hany Abd Elshakour, & Abdel-Hamid, 2006) "a systematic and continuous measurement process; a process of continuously measuring and comparing an organization's output against business leaders' outputs anywhere in the world which will help the organization to take action to improve its performance." In these previous definitions, the concept of benchmarking is concentrated in two main activities: measuring and comparing labor productivity. Many researchers have studied the topic of benchmarking and created a baseline of construction activity. Much of this literature is presented below.

(Jarkas & Horner, 2015) developed a rigorous approach to determining baseline labor productivity rates related to in situ reinforced concrete activities producing main building elements under normal operational circumstances in Kuwait. The data were collected using the international observation data collection technique, as applied to 208 cast-in-place reinforced concrete building projects. The researchers used box plots to analyze the data, finding that the Theoretical Model for International Benchmarking of Labor Productivity (TMIBLP) was not effective for creating a baseline for formwork activities. For each dataset collected, the maximum, upper quartile, median, lower quartile, and minimum values of labor productivity for the activities studied were calculated and presented. The median represented the baseline of labor productivity and the intermediate quartile range indicated the labor productivity range. The upper and lower quartiles were used to identify poor and outstanding labor productivity. The productivity rates they calculated are presented in Table 1.

Element	Formwork baseline labor productivity (M^2/MH)	Element	Rebar installation baseline labor productivity (KG/MH)	Element	Pumped Concreting baseline labor productivity (M^3/MH)
Isolated Foundation	1.78	Isolated Foundation	75	Isolated Foundation	1.5
Raft Foundation	2.3	Raft Foundation	175.44	Grade Beams	1.67
Grade Beams	2.33	Columns	75.42	Rafts, Grade Slabs, Floors	2.32
Columns	1.67	Beams	67.54		
Beamless Slabs	4.61	Slabs	100.79		
Beam-Slab Floors	1.97				

Table 1:Data of Formwork, Rebar Installation, and Pumped Concrete: Baseline Labor Productivity in Kuwait

(Thomas H. R., 2015) developed a procedure for establishing labor productivity benchmarks, based on the answers to six questions: 1) What is the objective? 2) How will performance be assessed? 3) What is best? 4) What is the selected practice for evaluation? 5) What is the fundamental principle? and 6)Why is the project best? The researcher applied this procedure to a case study of three ongoing construction projects.

(Ghoddousi, Alizadeh, Hosseini, & Chileshe, 2014) presented a framework for improving the reliability of the TMIBLP method for different construction activities in Iran. They began by identifying difficulties uncovered in previous studies implementing the TIMBLE and then explained how these problems were overcome by their model. They also determined a baseline for erecting steel structures in Iran: 2.07hr/ton.

(Zhao & Dungan, 2014) discussed several methods for calculating lost productivity, and identified their advantages and drawbacks. They then proposed a new method they called the improved baseline method, a mitigated process they claimed would overcome the drawbacks and leverage the advantages of the TMIBLP process proposed by (Thomas & Završk, 1999). They explained the method as: "dividing the productivity data into two groups, the unimpacted/lightly impacted and the heavily impacted, using the overall average productivity. Then the baseline is refined from the unimpacted group by eliminating extreme data points that may not reflect the contractor's normal productivity levels." Finally, they compared their proposed method with others, using a numerical example to illustrate the advantages and explain how their method overcame the drawbacks of others.

(Manoliadis, 2011) discussed the TMIBLP approach for benchmarking labor productivity in Greece and implemented its principles to analyze the construction project labor productivity data of four construction projects. The author calculated the indices of the TMIBLP method, which are: distribution index (DI), performance ratio (PR), and project management index (PMI) (Thomas & Završk, 1999). From the results, he was able to determine the best and worst performing projects and compare them to the actual project situations, concluding that the benchmarking indices used in the TMIBLP approach were good indicators for judging labor productivity in construction projects.

(Abdel-Razek, Hany Abd Elshakour, & Abdel-Hamid, 2006) examined two concepts related to lean construction, benchmarking and reducing variability in labor productivity. They used the productivity data from the masonry activities of 11 Egyptian projects. The benchmarking indices of DI, PR, and PMI were calculated to determine the best and worst performing projects. Labor productivity variance was also measured using the coefficient of productivity variation. The correlation between labor productivity variability and task performance was also analyzed. It was concluded that labor productivity benchmarks were good tools for measuring project performance, and variability in labor productivity was found to be a useful means of differentiating between high and low levels of performance.

(Thomas & Završk, 1999) developed the TMIBLP, which is the basis of many studies seeking to develop labor productivity standards and measure project performance. Many researchers have argued that this approach it is not reliable when it comes to developing standardized productivity rates. This model is basically related to baseline productivity, which is established according to the productivity measurements of the highest 10% of working days in terms of the daily productivity of the total working days. In order to simplify the model, the researchers presented a step-by-step procedure. 1) Calculate the number of days that represent 10% of the total working days with the highest productivity, and round that number to the next highest odd number. The result should be less than five days (the subset *n*). 2) Determine the baseline productivity of n working days that have the highest daily production. 3) For the *n* days determined in Step 2, record the daily production. 4) The median of the daily productivity measurements of *n* working days represents the baseline of labor productivity. In addition, this research developed indices for measuring project performance. DI is the ratio of the abnormal/disrupted workdays to the total number of workdays, PR is the ratio of the cumulative productivity to the estimated productivity, and PMI is the ratio of the cumulative productivity minus the baseline productivity to the expected baseline productivity. This index represents how project management affects productivity. The researchers developed a hypothesis for evaluating masonry productivity data from 23 real-world projects and tested it against the concrete formwork activity of eight project datasets of productivity and 12 project databases of structural steel erection. They also presented strong support for their hypothesis using two additional databases.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter presents the steps followed to achieve the set objectives. The data required, data collection process, population and sample size determination, and data analysis are all presented in the following sections.

3.1 Data Required

Formwork can take many shapes. It is practical to divide the required data into subgroups with similar characteristics. One group of data analyzed in this research is columns. All columns examined here were of a rectangular or square shaped. The variables were crew size, average temperature during the work, Hight of pouring, and number of working floors. For the slab group, only beam-supported slabs were examined. The variables were crew size, average temperature during the work, number of working floors, slab thickness, and maximum span. For foundations, the third group, the variables were crew size, average temperature during the work, depth of the foundation, and foundation thickness. The data required are summarized below.

Foundation Formwork

Quantity of installed formwork (plywood or timber) measured in square meters of contact area (m^2).

Number of working hours required to erect the formwork.

Daily working hours (DWH).

Crew size.

Depth of foundation: the difference between natural ground level and bottom of the foundation level (base level) / (m).

Foundation thickness / (m).

Average temperature during the work / (C°).

Column Formwork

Quantity of installed formwork measured in square meters of contact area (m^2).

Number of working hours required to erect the formwork.

DWH.

Crew size.

Hight of pouring: the height of the column according to the drawings / (m).

Floor number: the number of working floors.

Average temperature during the work / (C°).

Slab Formwork

Quantity of installed formwork measured in square meters of contact area (m^2).

Number of working hours required to erect the formwork.

DWH.

Crew size.

Slab thickness / (m).

Floor height: the distance between the slab surface of one floor and the bottom of the following slab.

Maximum span: maximum clear distance between two supports in the design of the slab.

Floor number: the number of working floors.

Average temperature during the work / (C°).

3.2 Data Collection

The required data were collected from contractors' historical records and direct measurements at ongoing construction sites. The data were collected via a form developed for this research. Each form was designed to obtain direct data related to productivity and other data regarding certain variables that affect productivity, excluding data for projects with abnormal variables (which will be analyzed in future studies). For all activities, data collection occurred in three sections. The first stage identified project characteristics such as project type and location, respondent's position, type of formwork activity, and execution crew (either direct labor or sub-contracted). The second stage identified the quantity of work, either from drawings or site measurements, and the time required to finish the work (TRFW). We then recorded data for variables related to each activity. Different variables affected some activities, but not all. The third stage involved recording if there were any delays or reasons for the work to be stopped. A copy of the instrument used for data collection is available in Appendix A.

The questionnaires were administered via email (Google) or by face-to-face interviews. During interviews, the researcher asked for permission from the interviewee to visit their construction site and collect the required data.

3.3 Working Conditions

In order to obtain reliable outcomes, we needed to identify general conditions for work in the sampled projects, ensuring that each had similar conditions.

- Between 8 and 10 DWH.
- Columns between 2.5 m and 4 m.
- Slab thickness between 18 cm and 45 cm.
- Floor height between 2.8 m and 4.3 m.
- Maximum span between 5 m and 10 m.

3.4 Population and Sample Size

As mentioned in Chapter 1, Section 6, the targeted projects were villas and residential construction projects with a maximum of five floors, so the population was contractors performing these types of work. It was determined that 113 contractors certified by the Ministry of Municipal and Rural Affairs (fourth and fifth grade) performed such projects in Dammam, Khobar, and Dharan. As the population was relatively small, we sent the data collection forms to all candidates, using the contact information provided on the Ministry's website. In addition, site visits were made to some uncertified contractors specializing in these types of projects in order to collect data directly from the site.

3.5 Data Analysis

In order to create labor productivity rates for any activity, it is very important to understand the nature of the activity and factors affecting labor productivity. Much research has been conducted to determine the factors affecting labor productivity, project performance, and causes of delay in construction projects in Saudi Arabia, including but not limited to (Alsuliman, 2019), (Damanhouri & Divya , 2017), (Mahamid, 2016), (Elawi, Algahtany, & Kashiwagi, 2016), Shash and Alsagoub (2014) (Shash & Alsagoub, 2014), (Mahamid, Al-Ghonamy, & Aichouni, 2013), and (Al-Kharashi & Skitmore, 2009). In order to obtain the best results and develop productivity rates representing the normal condition of the targeted activity, it was required to study projects and labor productivity under the normal conditions of most of construction projects, and exclude cases with special characteristics.

From the literature review, we found that benchmarking and developing productivity rates have been topics of research for more than two decades. Many have developed procedures to determine such rates. Each has unique drawbacks and advantages, and none are applicable to all activities in the construction industry. In the previous chapter, we explained the improved baseline method developed by Zhao and Dungan (2014), and how it can be used to mitigate the subjectivity of the original TMIBLP method presented by Thomas and Zavrski (1999). However, the improved baseline method may not be suitable for creating baseline performance standards for labor productivity at the industry level, where productivity data classified as "good" for a certain project may still be lower than the average industry level, or vice versa

(Jarkas & Horner, 2015). The improved baseline method utilizes the mean instead of the median to classify the level of productivity. Such an approach has two additional drawbacks. First, the mean value can be misleading with regards to the central tendency, especially when labor productivity data do not follow the normal distribution pattern, which is often the case (Radosavljević & Horner, 2002) Second, even when the data are normally distributed, the mean value, unlike the robust median measure, is highly affected by extreme data, which may not be treated as outliers (Jarkas & Horner, 2015). For instance, we argue that it is not realistic to develop a baseline for an activity using the highest 10% of productivity performance for that activity where the baseline should represent the normal performance productivity. Moreover, the nature of formwork makes it impossible to track daily productivity because laying formwork depends on many other activities and cannot be measured directly. Thus, it is preferable to find the combined productivity of various formwork activities.

Consequently, we agree with Jarkas and Horner (2015) that the improved baseline method is not applicable to this research. Rather, a box plot analysis is the most appropriate and reliable method for reaching the goal of this type of study of Jarkas and Horner (2015) . This approach tracks formwork productivity and obtains the targeted data to perform box plot analyses for each set of data gathered for the same type of work. The productivity of formwork activities is then calculated using Equation 2 (see Chapter 2, Section 1) as follows:

$$\boldsymbol{P(formwork\ labor\ productivity)} = \frac{\boldsymbol{output\ \ quantity(m^2)}}{\boldsymbol{man - hours\ (h)}}$$

After calculating the productivity for each group, a boxplot is used to analyze the data and determine the five-number summary of the labor productivity values. Figure 2 illustrates the box plot characteristics and five-number summary of labor productivity values. The median is the middle (or center) value of the data and unaffected by extreme values (as is the case with the mean). Thus, the median is a reliable measurement and can be considered the productivity standard rate for each group.

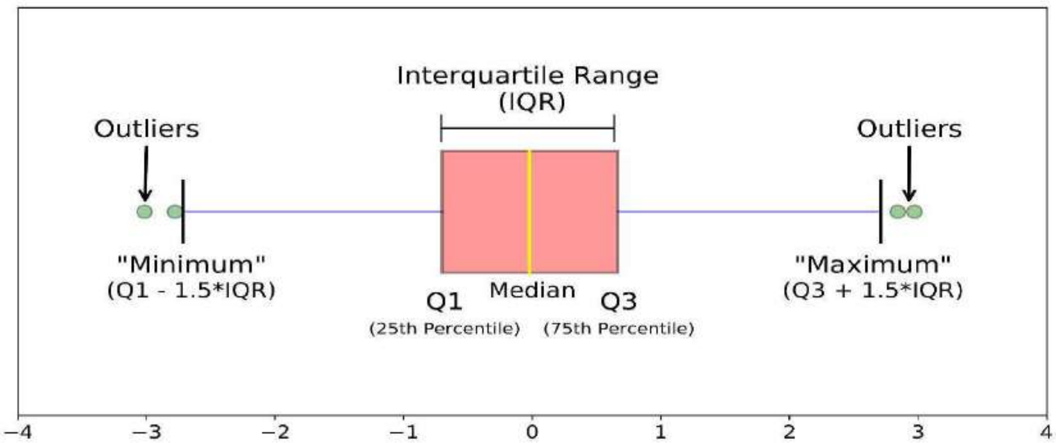

Figure 1: Box plot characteristics.

In a compression of the box plot with a probability density function for a normally distributed population with a mean of 0 and standard deviation of 1 (see Figure 3) (Benjamini,, 1988), the interquartile range (IQR) represents the middle range of the data values, where the spread is less than 1 standard deviation from the median. Thus, the IQR represents the normal productivity range. Any productivity data above Q3 can be considered above normal productivity, and any productivity data lower than Q1 can be considered below. Any data below (Q1-1.5*IQR) and above (Q3+1.5*IQR) are outliers and represent unusual performance, due to unique circumstances or measurement error.

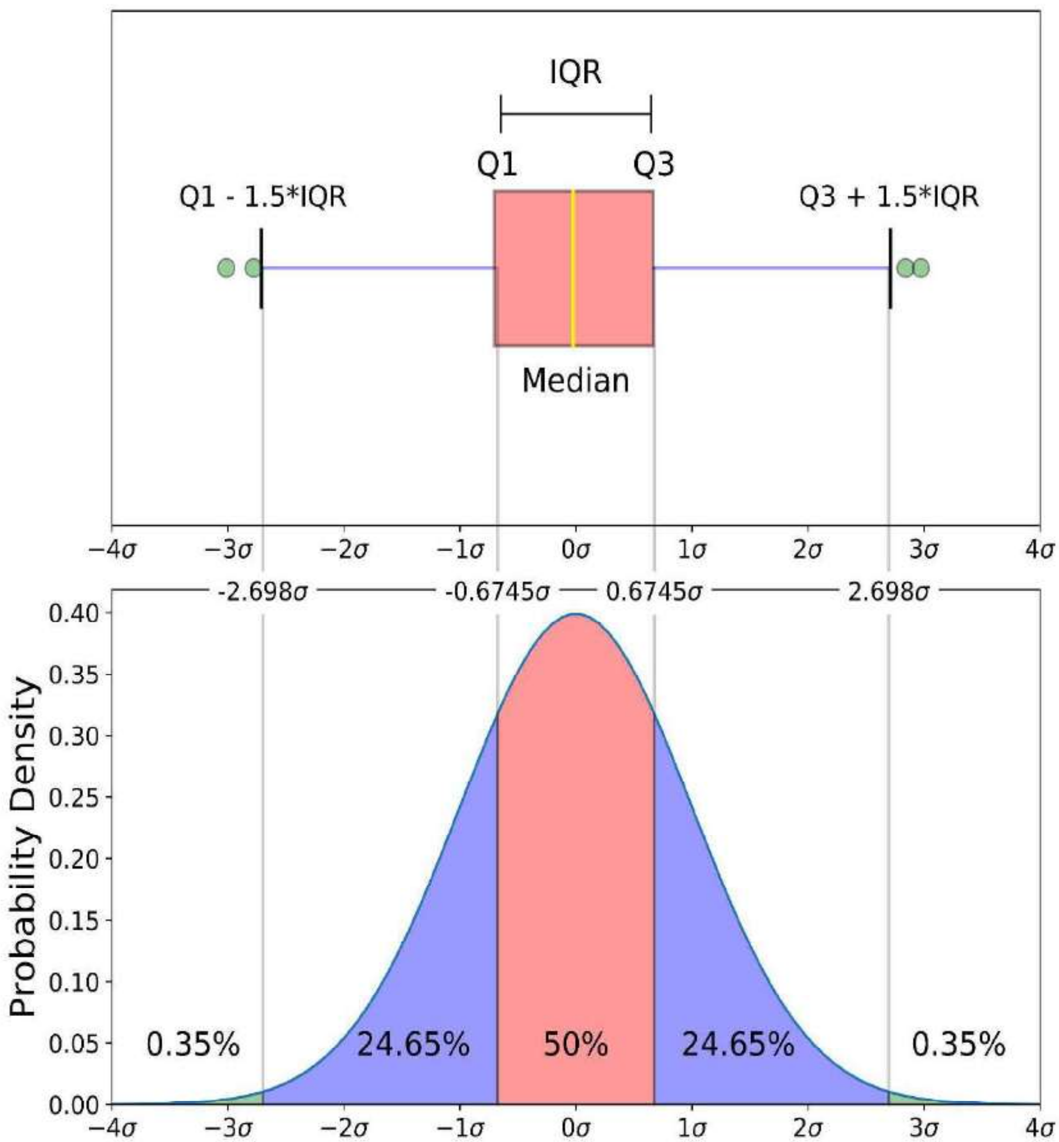

Figure 2: Box plot with normal distribution.

Figure 3 includes a flow chart of the procedure used in this research.

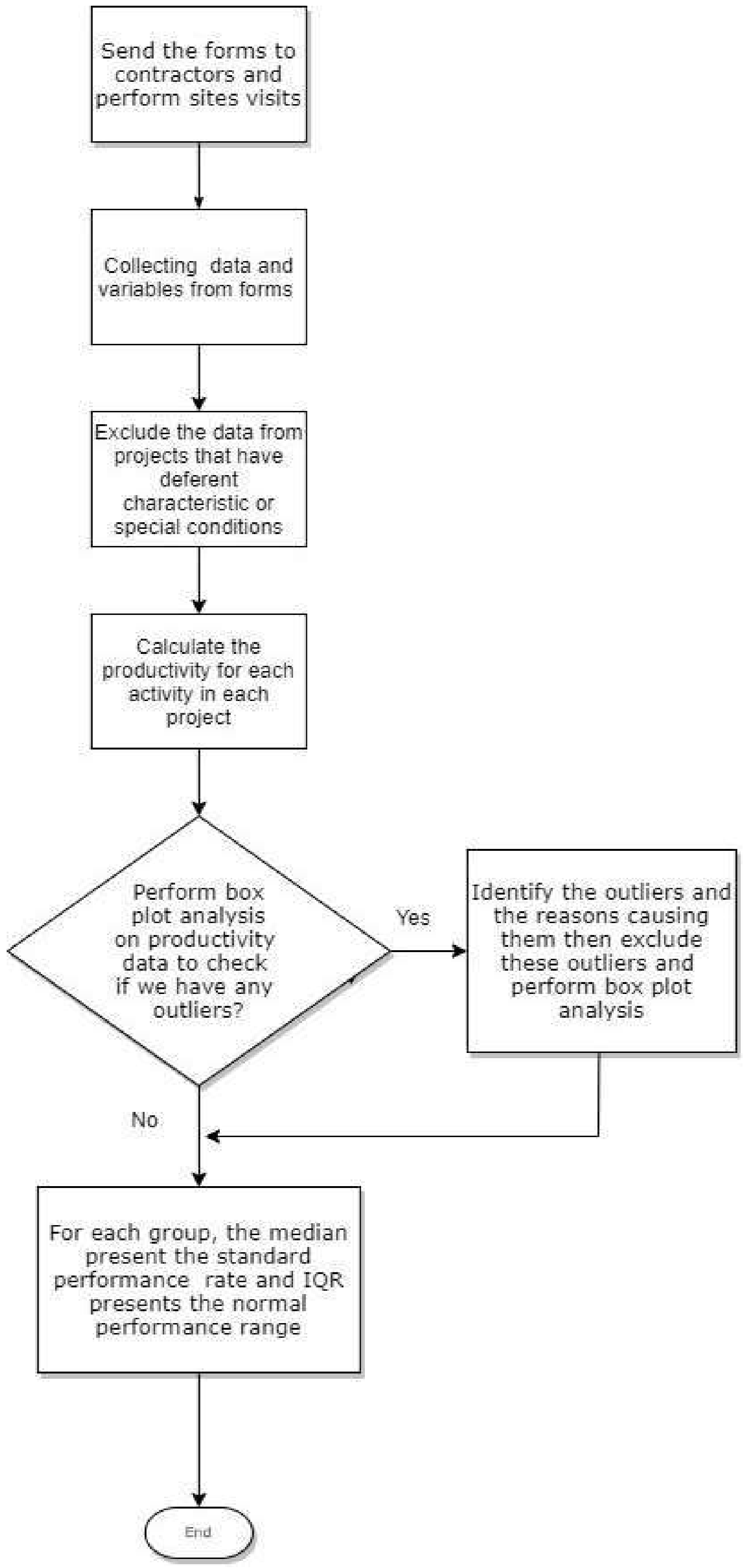

Figure 3: Research procedure.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the analysis of the data and a discussion of the results. The first section provides general information about the projects from which the data were calculated and the supervisors of these projects. The second section describes the mathematical analysis for each construction element and the resulting findings. The last section compares the findings of the research and two sets of data for two projects. The researcher was the project engineer for both of those projects and all the measurements were obtained from the site directly. Also, this section compares the findings with those of other studies conducted in the Gulf region.

4.1 Projects and Response General Information

4.1.1 Project Information

A total of 113 construction firms were contacted to participate in the study. Unfortunately, only five contractors responded and provided the requested data. The author, then, visited 28 ongoing construction projects and asked the permission from the project management to measure formwork productivity. Therefore, we were able to obtain full and reliable productivity information from 33 projects. Thirty-one were used to develop standard productivity rates, and two were used for comparison, since the researcher was directly supervising these. All projects were located across the Eastern Province, as shown in Figure 4. Fourteen were in Dammam, 10 in Khobar, and seven in Dharan. These projects included 19 private villas with three floors, eight residential buildings with three floors, and four residential buildings with five floors, as shown in Figure 5.

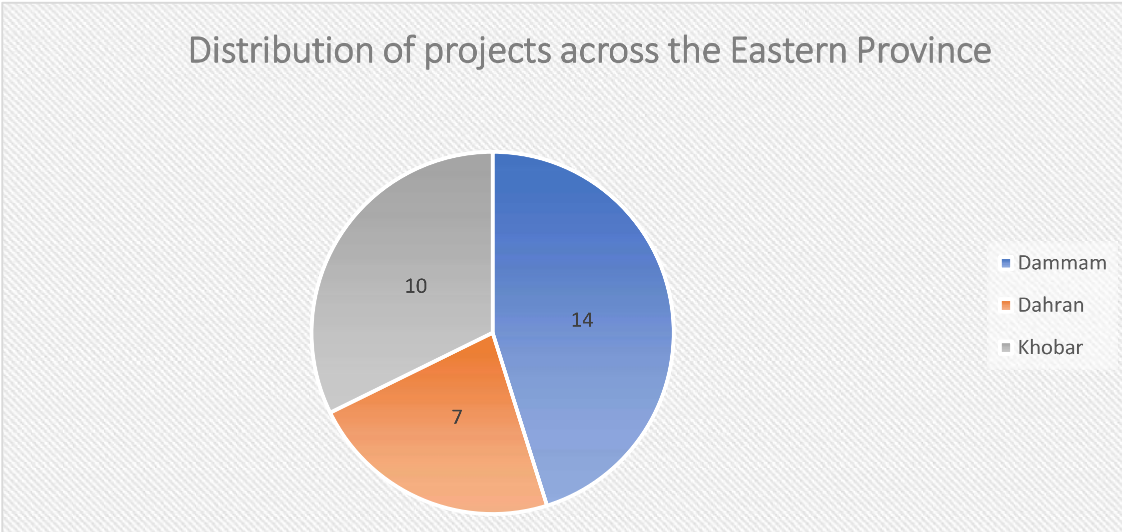

Figure 4: Projects distribution across the Eastern Province.

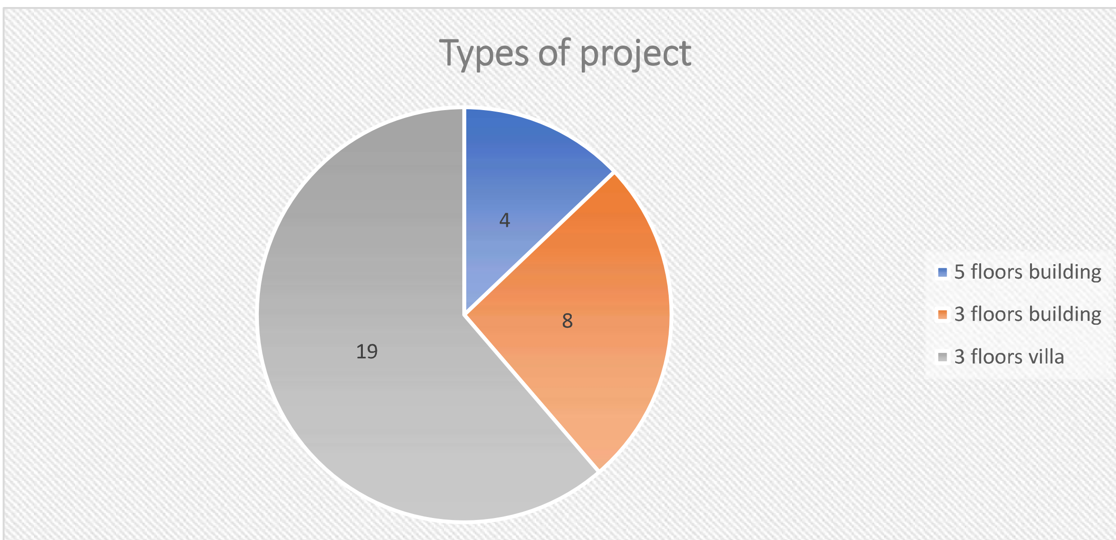

Figure 5: Projects types.

All of these projects were supervised by someone from the contractor firm. The education levels of the supervisors varied between engineers and foremen, and their experience ranged from six to 19 years, so all data provided was considered reliable.

4.1.2 Response information

From the 31 projects, we collected 161 productivity datapoints for all formwork activities. The distribution of productivity datapoints among the structural elements is shown in Table 2.

Structural Element	Productivity Datapoints
Foundation	30
Column	65
Slab	66

Table 2: Distribution of Productivity Datapoints for Structural Elements

Respondents' were responsible for directly tracking these activities. There were nine project engineers, seven project managers, five planning engineers, and three foremen. The distribution of respondents' positions is presented in Figure 6.

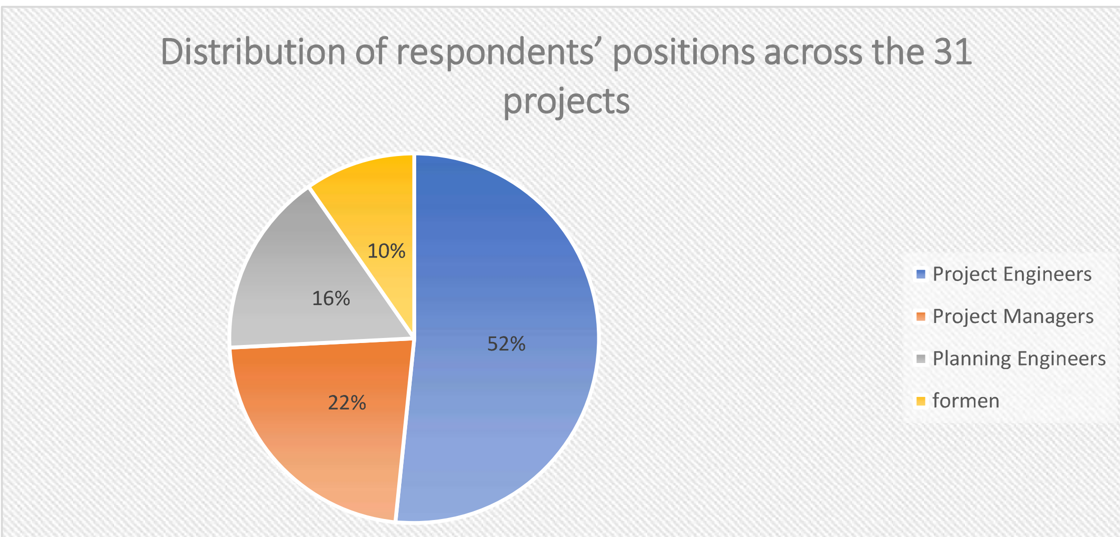

Figure 6: Respondents' positions in the 31 projects examined.

Due to the Covid-19 pandemic and the precautionary measures required by the Ministry of Health, the data collection process was divided into two periods. The first was before restrictions on movement, from January through March 2020. The second period was after the restriction of movement, from June through November 2020. These two periods had different weather conditions. The first had milder temperatures (20°C to 30°C) and was considered the best work period in Saudi Arabia in terms of weather. The second period featured higher temperatures (30°C to 48°C), with high levels of humidity that some days greatly affected productivity. In most cases, the work on site had to be stopped. Thus, in order to obtain the most reliable and applicable outcomes, all data gathered in harsh weather (high temperature with high levels of humidity) were ignored. In addition, all contractors providing data used their own manpower. Working hours were approximately eight to nine hours per day. The nationalities of the crews for the 31 projects were nine Syrians, 11 Egyptians, eight Indians, and three Bangladeshis. The percentages of these nationalities are shown in Figure 7.

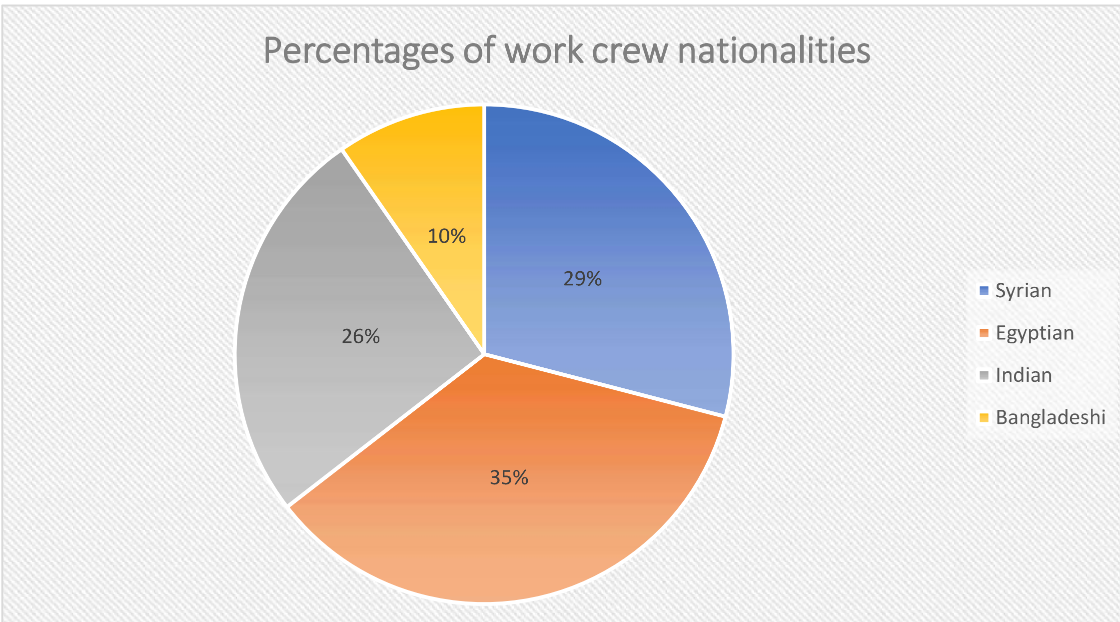

Figure 7: Percentage of nationalities of working crews.

With regards to foundation data, depths varied from 1 m to 2.4 m, while foundation thickness was between 0.5 m and 0.6 m. For columns, the height of pouring ranged from 2.7 m to 3.7 m. All productivity data were measured for rectangular or square-shaped columns, as mentioned in Chapter 3. Finally, for slab productivity, the thickness ranged from 0.3 m to 0.32 m, and the floor height varied between 3 m and 3.9 m. The maximum span ranged between 3 m and 7.6 m.

As argued by Shash and Alsagoub (2014), the quality of engineering drawings and other factors may affect labor productivity, especially engineering office factors such as design and approval, so to minimize the effects of these factors, we obtained data from projects designed and supervised by engineering offices located in the Eastern Province who were well-known for their efficiency. All followed the same design and supervision concepts.

4.2 Results of the Analysis

This section provides the statical analysis of the data. The outcomes of this analysis were used to develop productivity standards for formwork activities in Saudi Arabia. The following sub-sections present the statical analyses for each structural element.

4.2.1 Foundation productivity data analysis

This research applied a box plot statical analysis to process the productivity data. The data for foundations appears below, in Table 3.

Productivity Data: Foundations														
Project number	Type of foundation	Crew nationality	Foundation depth	Depth of foundation	Average temp	Crew members		Crew working hours	Time required to finish the work		Daily working hours	Total working hours	Formwork quantity	Skilled labor productivity
			m	m	℃	skilled	non-skilled	h	days	hours	h	h	m2	m2/h
1	Strip	India	0.5	1.5	25-30	3	1	3.5	2	4	8	70	138.1	1.973
2	Strip	Egypt	0.5	1.5	25-30	3	1	3.5	2	5	8	73.5	144.5	1.966
3	Strip	India	0.6	1.8	25-30	2	2	3	3		9	81	159	1.963
4	Isolated	Egypt	0.5	1	25-30	2	1	2.5	2	5	8	52.5	101	1.924
5	Isolated	Egypt	0.5	1.5	25-30	2	2	3	2		9	54	108.8	2.015
6	Strip	Egypt	0.5	2	25-30	2	1	2.5	2		9	45	92.3	2.051
7	Isolated	Syria	0.5	1.8	25-30	2	1	2.5	2		8	40	80.8	2.020
8	Strip	Syria	0.5	2	25-30	2	1	2.5	2	5	9	57.5	112.6	1.958
9	Strip	India	0.5	1.3	25-30	3	2	4	3		9	108	226	2.093
10	Isolated	India	0.5	2	25-30	2	2	3	2	3	9	63	122	1.937
11	Isolated	Syria	0.5	1.7	25-30	2	2	3	2		9	54	114.2	2.115
12	Isolated	Syria	0.5	1.5	25-30	2	1	2.5	2	2	9	50	103.5	2.070
13	Strip	Egypt	0.5	1.6	40-48	3	2	4	2	4	8	80	144.05	1.801
14	Strip	Egypt	0.6	1.8	40-48	2	2	3	3		9	81	149.04	1.840
15	Strip	Egypt	0.5	2.4	40-48	2	1	2.5	2		9	45	77.48	1.722

Productivity Data: Foundations														
Project number	Type of Foundation	Crew nationality	Floor	Slab thick-ness	Average temp	Crew members		Crew working hours	Time required to finish the work		Daily working hours	Total working hours	Slab usable surface	Skilled labor productivity
				m	℃	skilled	non-skilled	h	days	hours	h	h	m^2	m^2/h
16	Isolated	Syria	0.6	2	40-48	3	1	3.5	3	3	9	105	171.48	1.633
17	Strip	India	0.5	1.9	40-48	2	1	2.5	2		9	45	81.8	1.818
18	Isolated	Syria	0.5	1.5	40-48	2	1	2.5	3		9	67.5	124.7	1.847
19	Isolated	Bangladesh	0.5	1.8	40-48	2	1	2.5	3		8	60	102.8	1.713
20	Strip	India	0.55	1.5	40-48	2	1	2.5	2		9	45	83.93	1.865
21	Strip	Bangladesh	0.5	1.9	40-48	2	1	2.5	2	5	9	57.5	99.7	1.734
22	Isolated	Egypt	0.5	1.6	40-48	2	1	2.5	2	4	9	55	94.6	1.720
23	Strip	Egypt	0.5	2.2	40-48	2	2	3	2		9	54	102.6	1.900
24	Strip	Syria	0.6	1.8	40-48	3	1	3.5	3		9	94.5	161.52	1.709
25	Strip	Syria	0.5	2.4	40-48	2	1	2.5	3	4	9	77.5	132.75	1.713
26	Strip	Bangladesh	0.5	1.45	40-48	2	1	2.5	3		9	67.5	124.25	1.841
27	Strip	Egypt	0.5	1.5	40-48	2	1	2.5	3		9	67.5	119.5	1.770
28	Isolated	Egypt	0.5	1.5	40-48	2	1	2.5	3		9	67.5	128.25	1.900
29	Isolated	India	0.5	2	25-30	2	2	3	3		9	81	161.4	1.993
31	Isolated	India	0.5	1.4	30-40	2	2	3	2		9	54	111.43	2.064

Table 3: Productivity Data for Foundations

Columns from one to seven, presents the variables and the characteristic of each work activity for each project. The eighth column is crew working hours (CWH), which represents the total hours the crew worked, based on skilled labor working hours (SLWH) and considering that non-skilled labor working hours are half the SLWHs and calculated from Equation 5.

$$CWH = SLWH + (NSLWH \times 0.5)$$

Equation 5: Crew Working Hours

As an example, the CWH for Project 1 were calculated as follows:

CWH = 3 + (1×0.5) = 3.5 hours

The ninth column shows the TRFW, determined through observations, time recordings, and the attendance sheets of the contractors for each project. The tenth column provides the DWH for each crew, based on the policies and conditions for each project. The tenth column shows the total working hours (TWH) required to finish the work, which is calculated from Equation 3 and takes into consideration SLWHs.

$$\boldsymbol{TWH = \{\ \{TWFW(Days) \times\ DWH\}\ +\ TRFW(Hours)\}\ \times\ CWH}$$

Equation 6: Total Working Hours

To clarify the process, the TWH for foundation formwork activities in Project 1 using Equation 3 was calculated follows:

TWH = {(2×8) + 4)} × 3.5= 20 × 3.5 = 70 hours

The eleventh column is the FQ installed. These values were calculated from the approved engineering drawings for each project. The last column shows the productivity data calculated for each formwork activity (P) for each project, which were calculated from Equation 4.

$$\boldsymbol{P\ (m^2/\ h) = \frac{FQ\ (m^2)}{TWH\ (h)}}$$

Thus, for calculating the productivity for foundation formwork activities for Project 1, Equation 4 was applied, as follows:

P = $\frac{138.1}{70}$ = 1.973 $\boldsymbol{m^2}$/ h.

Using the same procedure for each activity and each project, we calculated the productivity data for all construction projects. These data are available in the last column of the productivity data table for foundations (see Table 2).

The next step was to sort the data in ascending order, in order to apply the box plot analysis:

{1.633, 1.709, 1.713, 1.713, 1.72, 1.722, 1.734, 1.77, 1.801, 1.818, 1.84, 1.841, 1.847,1.865, 1.874, 1.9, 1.924, 1.937, 1.958, 1.963, 1.966, 1.973, 1.993, 2.015, 2.02, 2.051, 2.064, 2.07, 2.093, 2.115}.

Using these sorted productivity data, we obtained the summary numbers for the box plot analysis: standard deviation (s): 0.1326, minimum value: 1.633, first quartile (Q1): 1.761, median (M): 1.9, third quartile (Q3): 2, and maximum value: 2.115 (see Figure 8).

Based on this analysis, we determined that the formwork labor productivity standard for foundation formwork was $\{\mathbf{1.9}\ \boldsymbol{m^2}/\ \textbf{skilled labor hour}\}$.

The range from Q1 to Q3 was $\{\mathbf{1.76},\ \mathbf{2}\}\boldsymbol{m^2}/\ \textbf{skilled labor hour},$ which was the normal productivity range for formwork activities related to foundations in the Eastern Province in Saudi Arabia.

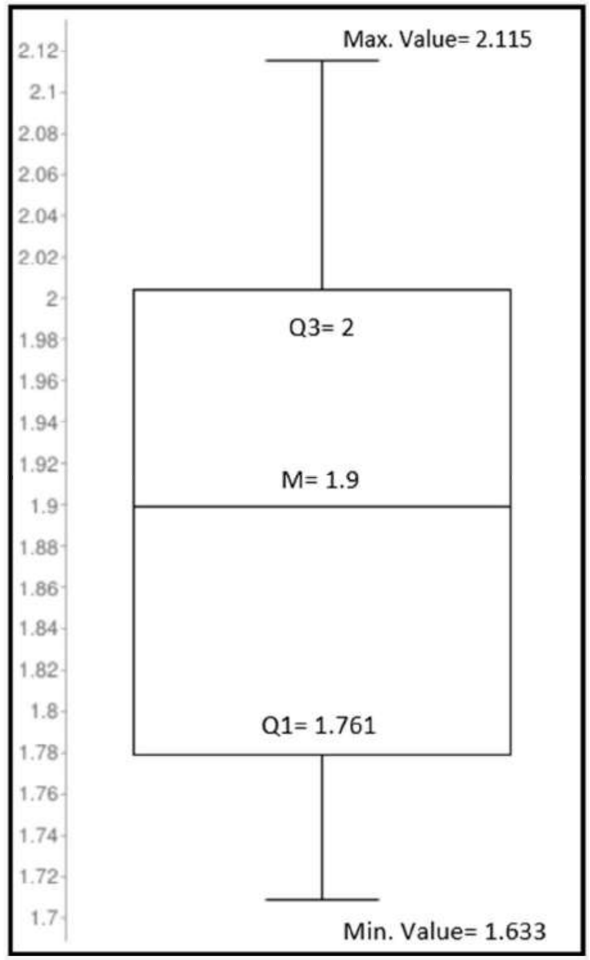

Figure 8: Box plot analysis of foundation productivity data.

4.2.2 Columns productivity data analysis

Following the same procedure for foundations, using Equations 2, 3, and 4 to calculate CWH, TWH, and P, we completed the productivity data table for columns (see Table 4).

Productivity Data: columns														
Project number	Crew nationality	Floor	Height of pouring	Average temp	Crew members		Crew working hours	Time required to finish the work		Daily working hours	Total working hours	Slab usable surface	Skilled labor productivity
			m	°C	skilled	non-skilled	h	days	hours	h	h	m^2	m^2/h
1	India	Ground	3.7	20-30	4	1	4.5	2	5	9	103.5	185.48	1.792
	India	First	3.7	25-30	4	1	4.5	2	5	9	103.5	183	1.768
2	Egypt	Ground	3.5	20-30	3	1	3.5	3	2	9	101.5	176.88	1.743
	Egypt	First	3.5	25-30	3	1	3.5	3	2	9	101.5	176.88	1.743
	Egypt	Second	3.5	40-48	3	1	3.5	4		9	126	176.88	1.404
	Egypt	Third	3.3	40-48	2	1	2.5	4	5	9	102.5	139.26	1.359
3	India	Ground	3.7	20-30	2	2	3	2	4	9	66	114	1.727
	India	First	3.7	25-30	2	2	3	2	3	9	63	114	1.810
	India	Second	3.7	40-48	3	1	3.5	1	5	9	49	73.26	1.495
4	Egypt	Ground	3.3	20-30	3	1	3.5	2	3	9	73.5	127	1.728
	Egypt	First	3.3	25-30	3	1	3.5	2	4	9	77	132.6	1.722
	Egypt	Second	3.3	40-48	2	1	2.5	2	6	9	60	86.5	1.442
5	Egypt	Ground	3.6	20-30	3	1	3.5	3	5	9	112	201.6	1.800
	Egypt	First	3.6	25-30	3	1	3.5	3		9	94.5	170.5	1.804
	Egypt	Second	2.7	40-48	2	1	2.5	2	4	9	55	75.6	1.375
6	Egypt	Ground	3.3	20-30	3	1	3.5	2		9	63	110.9	1.760
	Egypt	First	3.3	25-30	3	1	3.5	2		9	63	110.9	1.760
	Egypt	Second	3	40-48	2	1	2.5	2	5	9	57.5	77.7	1.351
7	Syria	Ground	3.4	20-30	2	1	2.5	3		9	67.5	118.83	1.760
	Syria	First	3.4	25-30	2	1	2.5	3		9	67.5	118.83	1.760
	Syria	Second	3.4	40-48	2	1	2.5	2	8	9	65	91.55	1.408

Productivity Data: Columns

Project number	Crew nationality	Floor	Height of pouring	Average Temp	Crew members		Crew working hours	Time required to finish the work		Daily working hours	Total working hours	Slab usable surface	Skilled labor productivity
			m	°C	skilled	non-skilled	h	days	hours	h	h	m^2	m^2/h
8	Syria	Ground	3.45	20-30	2	2	3	2	4	9	66	115.9	1.756
	Syria	First	3.3	25-30	2	2	3	3	5	9	96	168.3	1.753
	Syria	Second	3.3	40-48	2	2	3	4	2	9	114	168.3	1.476
	Syria	Third	3.3	40-48	2	2	3	3		9	81	118.14	1.459
9	India	Ground	3.4	20-30	3	2	4	3		9	108	185	1.713
	India	First	3.4	25-30	3	2	4	3		9	108	185	1.713
	India	Second	3.4	40-48	2	2	3	2	4	9	66	92.5	1.402
10	India	Ground	3.5	25-30	2	1	2.5	4		9	90	157.8	1.753
11	Syria	Ground	3.5	20-30	2	2	3	4		9	108	173.74	1.609
	Syria	First	3.5	25-30	2	2	3	4		9	108	173.74	1.609
	Syria	Second	3.5	40-48	2	1	2.5	2	4	9	55	72.1	1.311
12	Syria	Ground	3.3	20-30	2	1	2.5	3	3	9	75	127.4	1.699
	Syria	First	3.3	25-30	2	1	2.5	3	2	9	72.5	127.4	1.757
	Syria	Second	2.7	40-48	2	1	2.5	2		9	45	66.96	1.488
13	Egypt	Ground	3.5	40-48	3	2	4	4	3	8	140	191.1	1.365
14	Egypt	Ground	3.7	40-48	2	2	3	3	7	9	102	142.82	1.400
15	Egypt	Ground	3.9	40-48	2	1	2.5	3	3	9	75	106.08	1.414
16	Syria	Ground	3.7	40-48	2	2	3	5	4	9	147	207.2	1.410
17	India	Ground	3.6	40-48	2	2	3	3	3	9	90	126.72	1.408
18	Syria	Ground	3.5	40-48	3	2	4	3	4	9	124	177.1	1.428
19	Bangladesh	Ground	3.3	40-48	3	1	3.5	3	2	8	91	126.72	1.393
20	India	Ground	3.3	40-48	2	1	2.5	2	5	9	57.5	79.2	1.377
21	Bangladesh	Ground	3.3	40-48	2	2	3	2	4	9	66	95.7	1.450
22	Egypt	Ground	3.4	40-48	3	1	3.5	2	7	9	87.5	127.16	1.453

Productivity Data: Columns													
Project number	Crew nationality	Floor	Height of pouring	Average temp	Crew members		Crew working hours	Time required to finish the work		Daily working hours	Total working hours	Slab usable surface	Skilled labor productivity
			m	°C	skilled	non-skilled	h	days	hours	h	h	m²	m²/h
25	Syria	Ground	3.2	40-48	3	1	3.5	4		9	126	189.42	1.503
	Syria	First	3.2	40-48	3	1	3.5	4		9	126	193.92	1.539
	Syria	Second	3.2	40-48	3	1	3.5	4		9	126	193.92	1.539
	Syria	Third	3.3	30-40	3	1	3.5	3	4	9	108.5	193.92	1.787
	Syria	Fourth	3.2	30-40	3	1	3.5	2	4	9	77	143.36	1.862
26	Bangladesh	Ground	3.1	40-48	2	2	3	3		9	81	132.06	1.630
	Bangladesh	First	3	40-48	2	2	3	3		9	81	127.8	1.578
	Bangladesh	Second	3	40-48	2	1	2.5	2	6	9	60	94.2	1.570
27	Egypt	Ground	3.3	40-48	2	2	3	3	4	9	93	143.88	1.547
	Egypt	First	3.3	40-48	2	1	2.5	3	4	9	77.5	128.04	1.652
	Egypt	Second	3.3	30-40	2	1	2.5	2	3	9	52.5	94.38	1.798
28	Egypt	Ground	3.4	40-48	3	1	3.5	3	5	9	112	177.48	1.585
	Egypt	First	3.4	40-48	3	1	3.5	2	6	9	84	130.56	1.554
	Egypt	Second	3.4	30-40	2	1	2.5	2	3	9	52.5	88.36	1.683
29	India	Ground	3.3	25-30	2	2	3	4		9	108	202.62	1.876
	India	First	3.3	40-48	2	2	3	5		9	135	204.6	1.516
	India	Second	3.3	40-48	2	2	3	4	7	9	129	204.6	1.586
	India	Third	3.3	40-48	2	2	3	4	5	9	123	204.6	1.663
	India	Fourth	3.3	30-40	2	1	2.5	3	4	9	77.5	142.2	1.835
30	Syria	Ground	3.6	30-40	2	1	2.5	3	5	8	72.5	120.24	1.658

Table 4: Productivity Data for Columns

By sorting these data and applying a box plot analysis, we obtained the summary numbers, as follows: standard deviation (s): 0.1596, minimum value: 1.311, first quartile (Q1): 1.446, median (M): 1.609, third quartile (Q3): 1.755, maximum value: 1.876 (see Figure 9).

Based on the previous analysis, we determined that the formwork labor productivity standard for column-related formwork activity was $\{\mathbf{1.609}\ \boldsymbol{m^2}/\ \textbf{skilled labor hour}\}$.

The range from Q1 to Q3 was **{1.446, 1.755}**$\boldsymbol{m^2}$**/ skilled labor hour**, which presents the normal productivity range for formwork activities related to columns in the Eastern Province in Saudi Arabia.

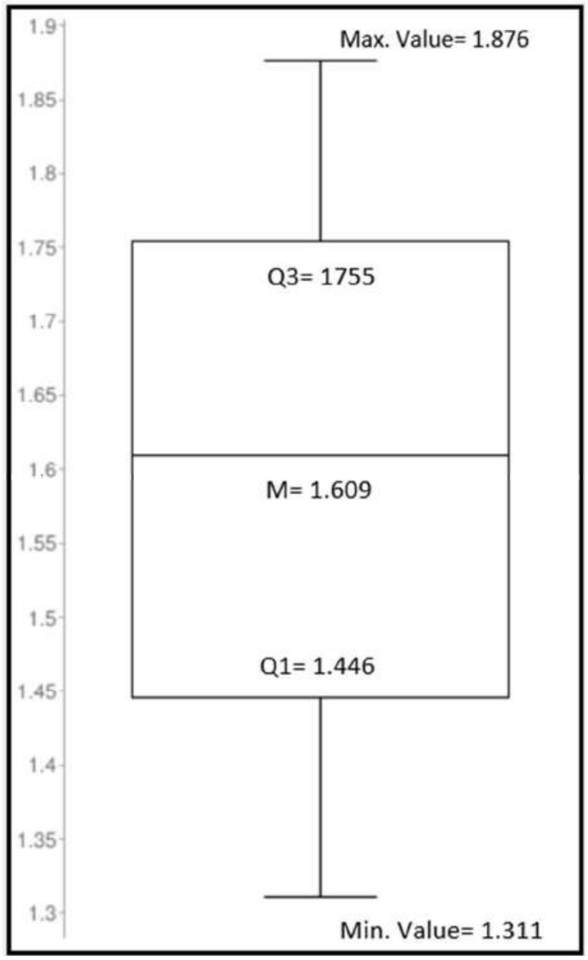

Figure 9: Box plot analysis of column productivity data.

4.2.3 Slab productivity data analysis

Following the same procedure as for the foundation and column data, we used Equations 2, 3, and 4 to calculate CWH, TWH, and P and complete the productivity data table for slab-related work (see Table 5).

Productivity data table for beam-supported slabs																
Project number	Type Of slab	Crew Nationality	floor	Slab Thick-ness	Floor height	Max Span	Average Temp	crew Members		Crew Working Hours	Time required To finish The work		Daily Working Hours	Total Working Hours	Slab Usable Surface	Skilled Labor productivity
				m	m	m	°C	Skilled	Non-skilled	h	days	hours	h	h	m^2	m^2/h
1	ripped	India	Ground	0.32	3.7	5	20-30	4	2	5	3	8	9	175	327.6	1.872
	ripped	India	First	0.32	3.7	5	25-30	4	2	5	3	7	9	170	327.6	1.927
2	ripped	Egypt	Ground	0.32	3.5	5.15	20-30	4	2	5	4	5	9	205	414.5	2.022
	ripped	Egypt	First	0.32	3.5	5.15	25-30	4	2	5	4	3	9	195	408	2.092
	ripped	Egypt	Second	0.32	3.5	5.15	40-48	4	2	5	5		9	225	408	1.813
	ripped	Egypt	Third	0.32	3.5	6.8	40-48	4	2	5	3		9	135	236	1.748
3	ripped	India	Ground	0.32	3.7	5.6	20-30	3	1	3.5	3		9	94.5	188.8	1.998
	ripped	India	First	0.32	3.7	5.6	25-30	3	1	3.5	3		9	94.5	188.8	1.998
	ripped	India	Second	0.32	3.7	3.8	40-48	2	1	2.5	2	4	9	55	85	1.545
4	ripped	Egypt	Ground	0.32	3.3	5.7	20-30	4	2	5	5		9	225	438.25	1.948
	ripped	Egypt	First	0.32	3.3	5.7	25-30	4	2	5	5		9	225	438.25	1.948
	ripped	Egypt	Second	0.32	3.3	5.7	40-48	3	1	3.5	4		9	126	219.75	1.744
5	ripped	Egypt	Ground	0.32	3.6	5.3	20-30	4	2	5	4		8	160	348	2.175
	ripped	Egypt	First	0.32	3.6	5.3	25-30	4	2	5	3	4	8	140	301	2.150
	ripped	Egypt	Second	0.32	2.7	5.3	40-48	3	1	3.5	3		8	84	144	1.714
6	ripped	Egypt	Ground	0.32	3.5	5.9	20-30	4	2	5	3		9	135	262.5	1.944
	ripped	Egypt	First	0.32	3.5	5.9	25-30	4	2	5	3		9	135	262.5	1.944
	ripped	Egypt	Second	0.32	3	6	40-48	3	1	3.5	2	4	9	77	131.4	1.706
7	ripped	Syria	Ground	0.32	3.7	7.6	20-30	2	2	3	5		9	135	283	2.096
	ripped	Syria	First	0.32	3.7	7.6	25-30	2	2	3	5		9	135	283	2.096
	ripped	Syria	Second	0.32	3.7	6.3	40-48	2	2	3	3	2	9	87	155	1.782
8	ripped	Syria	Ground	0.32	3.45	6.5	20-30	3	2	4	7		9	252	549.87	2.182
	ripped	Syria	First	0.32	3.3	6.5	25-30	3	2	4	7		9	252	544	2.159
	ripped	Syria	Second	0.32	3.3	6.5	40-48	3	2	4	8	7	9	316	544	1.722
	ripped	Syria	Third	0.32	3.3	5.75	40-48	3	1	3.5	3	2	9	101.5	171.44	1.689

Productivity data table for beam-supported slabs

Project number	Type Of slab	Crew Nationality	floor	Slab Thick-ness	Floor height	Max Span	Average Temp	crew Members		Crew Working Hours	Time required To finish The work		Daily Working Hours	Total Working Hours	Slab Usable Surface	Skilled Labor productivity
				m	m	m	℃	Skilled	Non-skilled	h	days	hours	h	h	m^2	m^2/h
	ripped	India	Ground	0.32	3.4	7	20-30	4	2	5	4		9	180	399	2.217
9	ripped	India	First	0.32	3.4	7	25-30	3	2	4	4	4	9	160	323.5	2.022
	ripped	India	Second	0.32	3.4	6.7	40-48	2	2	3	5		9	135	229.76	1.702
10	ripped	India	Ground	0.32	3.8	5.3	20-30	3	1	3.5	5		9	157.5	293	1.860
	ripped	Syria	Ground	0.32	3.5	6.2	20-30	3	2	4	4	5	9	164	334	2.037
11	ripped	Syria	First	0.32	3.5	6.2	25-30	3	2	4	4	5	9	164	334	2.037
	ripped	Syria	Second	0.32	3.5	5.25	40-48	2	2	3	3		9	81	147.84	1.825
	ripped	Syria	Ground	0.32	3.3	5.7	20-30	3	2	4	5		9	180	375.6	2.087
12	ripped	Syria	First	0.32	3.3	5.7	25-30	3	2	4	5		9	180	375.6	2.087
	ripped	Syria	Second	0.32	3.3	5.7	40-48	2	2	3	4		9	108	198.2	1.835
13	ripped	Egypt	Ground	0.32	3.2	6	40-48	3	2	4	8		8	256	418.32	1.634
14	ripped	Egypt	Ground	0.32	3.7	5.8	40-48	3	2	4	6		9	216	356.56	1.651
15	ripped	Egypt	Ground	0.32	3.9	5.2	40-48	2	2	3	4	5	9	123	204.87	1.666
16	ripped	Syria	Ground	0.32	3.7	7	40-48	4	2	5	6	5	9	295	466.9	1.583
17	ripped	India	Ground	0.32	3.6	6.1	40-48	3	2	4	6		9	216	332.32	1.539
18	ripped	Syria	Ground	0.32	3.5	5.9	40-48	3	2	4	7		9	252	445.33	1.767
19	ripped	BANGLADISH	Ground	0.32	3.3	4.9	40-48	4	2	5	5	5	8	225	373.26	1.659
20	ripped	India	Ground	0.32	3.3	6.35	40-48	3	1	3.5	5		9	157.5	251.15	1.595
21	ripped	BANGLADISH	Ground	0.32	3.3	6.4	40-48	3	2	4	6		9	216	345.3	1.599
22	ripped	Egypt	Ground	0.32	3.4	6	40-48	5	2	6	4		9	216	350.2	1.621
23	ripped	Egypt	First	0.32	3.4	6	40-48	4	2	5	4		9	180	303.44	1.686
	ripped	Syria	Ground	0.32	3.5	6	40-48	3	2	4	7	3	9	264	464.9	1.761
	ripped	Syria	First	0.32	3.5	6	40-48	3	2	4	7		9	252	452	1.794
25	ripped	Syria	Second	0.32	3.5	6	40-48	3	2	4	7		9	252	452	1.794
	ripped	Syria	Third	0.32	3.5	6	30-40	2	2	3	8		9	216	452	2.093
	ripped	Syria	fourth	0.32	3.5	6.4	30-40	2	2	3	4		9	108	208.2	1.928
	ripped	BANGLADISH	Ground	0.3	3.4	6.5	40-48	3	2	4	5		9	180	340.88	1.894
26	ripped	BANGLADISH	First	0.3	3.3	6.5	40-48	3	2	4	5		9	180	334.5	1.858
	ripped	BANGLADISH	Second	0.3	3.3	6.5	40-48	2	2	3	3	5	9	96	175.42	1.827

Productivity data table for beam-supported slabs																
Project number	Type Of slab	Crew Nationality	floor	Slab Thick-ness	Floor height	Max Span	Average Temp	crew Members		Crew Working Hours	Time required To finish The work		Daily Working Hours	Total Working Hours	Slab Usable Surface	Skilled Labor productivity
				m	m	m	°C	Skilled	Non-skilled	h	days	hours	h	h	m^2	m^2/h
27	ripped	Egypt	Ground	0.3	3.4	4.6	40-48	3	1	3.5	5	4	9	171.5	295.56	1.723
	ripped	Egypt	First	0.3	3.4	4.6	40-48	3	1	3.5	5	3	9	168	295.56	1.759
	ripped	Egypt	Second	0.3	3.4	4.35	30-40	2	2	3	3		9	81	155.7	1.922
28	ripped	Egypt	Ground	0.32	3.7	6.8	40-48	2	2	3	7		9	189	385.15	2.038
	ripped	Egypt	First	0.32	3.7	6.1	30-40	2	2	3	6		9	162	350	2.160
	ripped	Egypt	Second	0.32	3.7	6	30-40	2	2	3	4		9	108	209	1.935
29	ripped	India	Ground	0.32	3.5	6	20-30	4	2	5	7		9	315	637	2.022
	ripped	India	First	0.32	3.5	6	40-48	4	2	5	8	2	9	370	662.54	1.791
	ripped	India	Second	0.32	3.5	6	40-48	4	2	5	8		9	360	662.54	1.840
	ripped	India	Third	0.32	3.5	6	30-40	4	2	5	7		9	315	662.54	2.103
	ripped	India	fourth	0.32	3.5	6.4	30-40	3	2	4	4	3	9	156	342	2.192
30	ripped	Syria	Ground	0.32	3.9	5.2	30-40	2	2	3	6		8	144	270	1.875

Table 5: Productivity Data for Beam-Supported Slabs

By sorting the productivity data, we were able to obtain the summary numbers for the box plot analysis: standard deviation (s): 0.1846, minimum value: 1.539, first quartile (Q1): .1723, median (M): 1.866, third quartile (Q3): 2.037, and maximum value: 2.217 (see Figure 10).

Based on the previous analysis, we were able to determine that the formwork labor productivity standard for beam-supported slabs was {**1.866 m^2/ skilled labor hour**}.

The range from Q1 to Q3 was **{1.723, 2.037}m^2/ skilled labor hour**, which presents the normal productivity range of formwork activities related to beam-supported slabs in the Eastern Province of Saudi Arabia.

4.3 Results Comparison

In this section, we compare the results from two sources: the data collected from two ongoing projects under direct supervision of the researcher, and the productivity standards for reinforced concrete in Kuwait developed by Jarkas and Horner (2015).

4.3.1 Construction projects data comparison

The purpose of this comparison was to test actual data collected from two construction sites with similar characteristics, which were used to calculate the productivity standards described above against the results of this research.

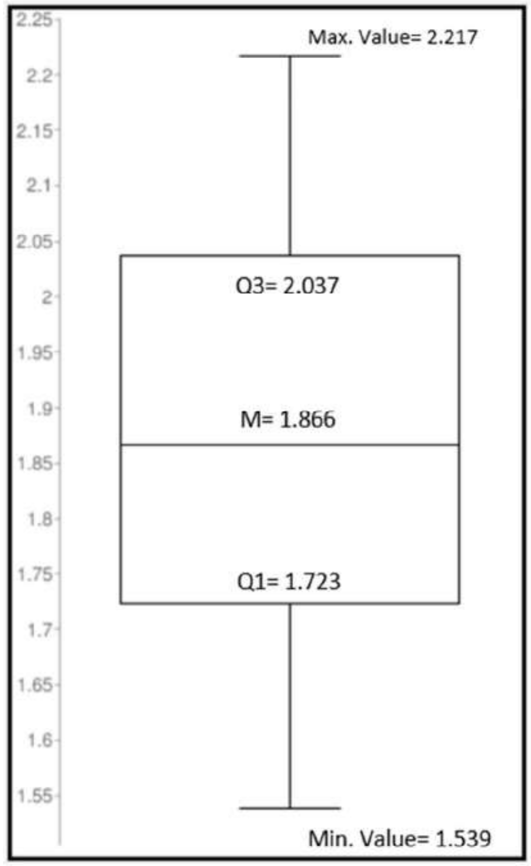

Figure 10: Box plot analysis beam-supported slab productivity data..

The first project was a private residential villa in the Al-Hussam district, Al-Khobar City, Eastern Province, Saudi Arabia. It was a three-story building (i.e., ground floor, first floor, and second floor) with a project area of 664 m^2. We will refer to this project as **Co-project 1**. The second project was a private residential building in the AL-Mazroia District, Dammam City, Eastern Province, Saudi Arabia. It was a five-story building (i.e., ground floor, first floor, second floor, third floor, and fourth floor), with a project area of 645 m^2. We refer to this project as **Co-project 2.** Both crews had significant experience in such projects, and executed them to a high level of quality. Both were delivered on time, taking into consideration the extended project deadlines due to movement restrictions in Saudi Arabia in response to the Covid-19 pandemic. The foundation formwork productivity data are available in Table 6.

Foundation Productivity Data: Co-projects 1 and 2														
Project number	Type of foundation	Crew nationality	Foundation depth	Depth of foundation	Average temp	Crew members		Crew working hours	Time required to finish the work		Daily working hours	Total working hours	Slab usable surface	Skilled labor productivity
			m	m	℃	skilled	non-skilled	h	days	hours	h	h	m2	m2/h
Co-project 1	Isolated	India	0.5	1.5	25-30	3	2	4	3	2	8	104	202.43	1.946
Co-project 2	Strip	Egypt	0.6	1	25-30	2	1	2.5	3		9	67.5	129.23	1.915

Table 6: Productivity Data for Foundations for Co-projects 1 and 2

We found that the data for both projects were little higher from our standard of 1.9 m^2/h, a difference of only about 2.3%, which mean that the labor productivity of these projects was good and within the normal productivity range. The formwork productivity data for columns are listed in Table 7. Some of these data were higher than our standard 1.609 m^2/h while the others were lower, so we can say that all the data which are above the standard were good productivity data, but we cannot say that the other data was bad as it is within the normal range with a maximum difference 5% from the standard.

Columns Productivity Data: Co-projects 1 and 2														
Project number	Crew nationality	Floor	Height of pouring	Average temp	Crew members		Crew working hours	Time required to finish the work		Daily working hours	Total working hours	Slab usable surface	Skilled labor productivity
			m	°C	skilled	non-skilled	h	days	hours	h	h	m²	m²/h
Co-project 1	India	Ground	3.3	20-30	2	1	2.5	3	6	8	75	127	1.693
	India	First	3.3	25-30	2	1	2.5	3	4	8	70	114.8	1.640
	India	Second	3.3	40-48	2	1	2.5	2	2	8	45	69.64	1.548
Co-project 2	Egypt	Ground	2.5	20-30	3	1	3.5	2		9	63	110	1.746
	Egypt	First	3.3	25-30	3	1	3.5	2	4	9	77	133.21	1.730
	Egypt	Second	3.3	40-48	3	1	3.5	2	6	9	84	133.21	1.586
	Egypt	Third	3.3	40-48	3	1	3.5	2	6	9	84	133.21	1.586
	Egypt	Fourth	3.3	40-48	2	1	2.5	2	3	9	52.5	81.6	1.554

Table 7: Productivity Data for Columns for Co-projects 1 and 2

Finally, the beam-supported slab data collected from both projects are available in Table 8.

Productivity data table for beam-supported slabs																
Project number	Type Of slab	Crew Nationality	floor	Slab Thick-ness	Floor height	Max Span	Average Temp	crew Members		Crew Working Hours	Time required To finish The work		Daily Working Hours	Total Working Hours	Slab Usable Surface	Skilled Labor productivity
				m	m	m	°C	Skilled	Non-skilled	h	days	hours	h	h	m²	m²/h
Co project 1	ripped	India	Ground	0.32	3.7	10	20-30	2	2	3	8	3	8	201	385.2	1.916
	ripped	India	First	0.32	3.7	10	25-30	2	2	3	8		8	192	385.2	2.006
	ripped	India	Second	0.32	3.7	10	40-48	2	2	3	6		8	144	268.3	1.863
co project 2	ripped	Egypt	Ground	0.32	2.5	8.5	20-30	4	2	5	5		9	225	430	1.911
	ripped	Egypt	First	0.32	3.3	8.5	25-30	4	2	5	5		9	225	430	1.911
	ripped	Egypt	Second	0.32	3.3	8.5	40-48	4	2	5	5	3	9	240	430	1.792
	ripped	Egypt	Third	0.32	3.3	8.5	40-80	4	2	5	5	3	9	240	430	1.792

Table 8: Productivity Data for Beam-Supported Slabs for Co-projects 1 and 2

Most of the data were higher than the standard, which is good, while the remaining data were lower from the standard with a maximum difference of 4% and this deference is acceptable where it is within the normal productivity range.

From the previous discussion, we could conclude that both projects had normal productivity rates and in some cases this productivity was higher than the standard which is good.

4.3.2 Comparison of other research data

This section offers a comparison of the results of this research with those of Jarkas and Horner (2015), which was conducted in Kuwait. Its objective was similar to the present study. Both works followed the same method when analyzing the data collected.

Both sets of research findings can be found in Table 9.

Findings		
Research	This study	Jarkas and Horner (2015)
Foundation	Isolated and strip foundation: 1.9 m^2/h	Isolated foundation: 1.78 m^2/h Raft Foundation: 2.3 m^2/h
Column	1.609 m^2/h	1.67 m^2/h
Slab	Beam-supported slab: 1.866 m^2/h	Beam-supported slab: 1.97 m^2/h Beamless slab: 4.61

Table 9: Research Findings for the Present Work and Jarkas and Horner (2015)

Jarkas and Horner (2015) developed standards for isolated and raft foundations of 1.78 m^2/h and 2.3 m^2/h, respectively, and normal productivity ranges of {1.5 m^2/h, 2 m^2/h} and {2.08 m^2/h, 2.5 m^2/h}, respectively. The present work developed a standard and normal productivity range of 1.9 m^2/h and {1.76 m^2/h, 2 m^2/h}. Our standard is between theirs. It is less than their raft foundation standard by 17.4% and higher than their isolated foundation standard by 6.3%. this deference is from the nature of the work as performing formwork for raft foundation is easier than other types and it is vice versa in the case of isolated foundation. Another area of difference, is that the developed standard for foundation includes all type of foundations and not limited to a specific type as the case of their research. the present research found 1.609 m^2/h to be the standard of column formwork productivity and {1.446 m^2/h, 1.755 m^2/h} the normal productivity range while Jarkas and Horner (2015) found the values to be 1.67 m^2/h and {1.43 m^2/h, 2.08}. We can see that both researches found almost the same values with very close deference of 3.6% and can be ignored taking into consideration that each project in construction industry is special and it is impossible to have two projects share the exact same characteristic and conditions. Finally, Jarkas and Horner (2015) found 1.97 m^2/h to be the standard productivity and {1.65 m^2/h, 2.36} the normal productivity range for beam-supported slabs, while our research found the values to be 1.866 m^2/h and {1.723 m^2/h, 2.037 m^2/h}. again, both researches found almost the same values with very close deference of 3.6% and can be ignored. From the previous comparison, we could conclude that both, Kuwait and Eastern province of Saudi Arabia almost shear the same standards for formwork activities for columns and beam-supported slabs while we can't say the same in case of foundations as the type of standard is deferent in both researches.

4.3.3 Validation of the obtained Standards

A face-to-face interview was conducted with three well experienced individuals who are working for contactors in the Eastern Province to seek their opinions on the developed productivity standards. At the beginning of the interview, the researchers described and explained in details the methodology that was followed to develop these productivity standards. Then, the researcher asked them to provide him with their assessment on the viability and validity of the productivity standards.

The first interviewee was a senior project engineer, with more than 15 years of experience working in a Grade Two contractor firm. He mentioned that they followed the same procedure to obtain such standards and expressed his appreciation for researchers interested in developing them. He felt this would encourage contractors to invest more in improving labor productivity, which in turn would positively affect the industry. He pointed out that our standards were close to real life and similar to the productivity rates they maintained, but couldn't provide us with details, due to company policy.

The second interviewee was a project manager with 10 years of experience in public housing projects, the focus of his company. He informed us that previously they used to perform these types of activities with their own labor, and their productivity rates were similar to our standards. At that time, though, they sub-contracted formwork activities. He mentioned that the reason behind this outsourcing was that the types of project they specialize in have limited execution periods, and sub-contractors specializing in such activities have higher rates of productivity than their own workforce, while the cost is much higher. Also, he believed that that the availability of such standards for construction activities would help contractors in estimating projects and finding their weaknesses related to productivity, so that these issues could be overcome.

The last interviewee was a small local contractor operating in the Eastern Province and specializing in private housing projects (villas and residential buildings). He uses his workforce to perform construction activities such as formwork, steel fabrication, and masonry. He informed us that they did not use any productivity rates to estimate the work. They used their experience to estimate the projects in total. He showed us his process for developing his own standards, but this failed due to limited resources. He believed that the availability of such standards would help the contractors in the market, especially when disputes arose.

4.4 Current productivity standard practices

After searching the industry for practices used by contractors in Saudi Arabia to obtain standardized rates, it was found that each contractor followed their own strategy, based on available resources. Big contracting firms have substantial resources and specialized teams to perform these tasks. For each work activity, they take different productivity data from their own projects with similar characteristics, work scope, and conditions. Then they organize these data in ascending order, and based on their experience they choose middle data to serve as a productivity rate that can be incorporated as a workforce production rate for this activity. This rate is used for bidding purposes, estimating the time and cost required for each activity, monitoring performance. These standards are updated every three, four, or five years, or whenever there is a difference between the actual productivity rate for an activity and their standard rate. In such cases, top management tracks the causes of such differences and determines if the standard productivity rate needs to be modified.

Small contractors with limited resources create their own productivity rates, either from the rates of other contractors (which is rare, since these are usually kept secret) or from international standards, other Gulf area standards, or standards published by unofficial publishers. Using their experience, they then modify the standards based on workforce performance.

CHAPTER FIVE

SUMMARY OF THE STUDY, CONCLUSIONS, AND RECOMENDATIONS

This chapter presents the findings of the present research. The first section provides a general idea of the study, showing the need for this research and its importance to the construction industry. The methodology used to achieve the research objectives and findings is explained in the second section, with a focus on the findings of this research. The third section describes the importance of these findings and how they may be used. The final section offers some ideas for future research that will enhance the findings obtained here and fill gaps in this area of research for Saudi Arabia.

5.1 Summary of the Study

In most nations, the construction industry is a major contributor to the economy. On average, it recruits 7% of the world's workforce and contributes approximately 9% to the GDP of developed countries (Horta, Camanho, Johnes, & Johnes, 2013). These values are even higher in developing countries. In Saudi Arabia, the construction industry is the second largest industry after oil and gas (Shash & Alsagoub, 2014). Moreover, Saudi Arabia leads the Gulf construction industry. The Kingdom plans to spend US$1.1 trillion on infrastructure projects alone in the next 20 years (Middle East Handbook, 2020). A large number of construction projects in Saudi Arabia involve building construction. The Saudi government is focusing on increasing the tourism sector in order to diversify the national income, since for decades it has depended on oil and gas. For instance, the Ministry of Housing announced 31 residential construction projects across the Kingdom, of which 11 are located in the Eastern Province. These will deliver 12,480 residential units (villas/residential buildings). These numbers don't include private building construction projects such as real estate development and individual home construction.

Reinforced concrete is the most frequently used material in construction projects in both the public and private sectors in Saudi Arabia, where structures range from single-family houses to high-rise buildings. Concrete building construction generally consists of three essential elements: foundations, columns, and slabs. The use of reinforced concrete is accomplished via three labor-intensive trades: formwork, rebar installation, and pouring concrete (Jarkas & Horner, 2015). Formwork is very important. “The cost of formwork is one-third to two-thirds of the overall costs of the reinforced concrete frame” (McTague & Jergeas, 2002). Thus, it is essential to have a good understanding of the activity and factors affecting productivity rates. The Saudi Arabian construction industry faces a very serious problem. There is lack of formal published standardized rates for most construction activities, especially formwork, and there are no known methods or procedures for contractors in Saudi Arabia to follow to identify appropriate productivity rates. Consequently, this study identified current practices for developing internal standards, in order to identify formwork labor productivity rates for the Eastern Province of Saudi Arabia, the largest province in Saudi Arabia and most substantial oil and gas industry in the world.

The data used in this study were gathered from 33 construction projects located in Dammam, Khobar, and Dharan in the Eastern Province. A boxplot analysis was performed on the data collected for the three key construction elements of foundations, columns, and slabs. From these data, summary numbers for the analysis for each construction element were obtained, allowing for the identification of standard productivity rates and normal productivity ranges for formwork activities. These rates for the various construction elements are presented in the following section.

5.2 Findings

5.2.1 Major findings

Using the collected productivity data, it was possible to determine the labor productivity standards for formwork activities in the Eastern Province. It was found that the labor productivity for foundation formwork was {**1.899** $\boldsymbol{m^2/}$ **skilled labor hour**} and **{1.77925, 2.0045}**$\boldsymbol{m^2/}$ **skilled labor hour** the normal productivity range. It was also found that {**1.609** $\boldsymbol{m^2/}$ **skilled labor hour**} was the labor productivity ratio for column formwork and **{1.406, 1.7565}**$\boldsymbol{m^2/}$ **skilled labor hour** the normal productivity range. Finally, {**1.866** $\boldsymbol{m^2/}$ **skilled labor hour**} was the labor productivity standard for slab formwork and **{1.688, 2.037}**$\boldsymbol{m^2/}$ **skilled labor hour** the normal productivity range.

Experts have agreed with the above productivity standards.

5.3 Conclusion

This research provides reliable and well-defined standards for formwork activities that stakeholders can use to accurately estimate the time and cost of these activities, and determine the optimum crew size in terms of both cost and time. Project management teams can use these standards to track the progress of their projects and identify factors affecting labor productivity, and if low, take corrective action.

5.4 Recommendations

The Chambers of Commerce or other Government agencies in Saudi Arabia are advised to adopt the process of developing productivity standards for all construction activities following the same procedures used in this research. They are also advised to update and publish to the public the standard productivities periodically. The adopting agency are directed to establish a unit within its organization to manage the productivity standards development and publication. The unit will collect the necessary data from contractors through a structured questionnaire.

Contractors in the Eastern Province, Saudi Arabia, are advised to consider the formwork standards that are published in this study as a benchmark for their measured productivity to evaluate how efficient their carpentry work.

New investors in the construction industry are advised to use the formwork standards that are published in this study as their estimated productivity for work they acquire.

5.5 Future Research

Future research should address other regions/provinces in Saudi Arabia and obtain similar standards. Future work could also explore productivity standards for different types of construction activities. Another interesting topic would be collecting data similar to this research data for each type of formwork, including timber with plywood, steel, aluminum, plastic, magnesium, and fabric. The productivity could then be calculated, as well the cost allocated for these activities, eventually providing a model recommending the optimum type of formwork for use in a construction project based on the time and cost allocated and importance of the activity.

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Appendix-A

Data collection form

نموذج جمع البيانات

<u>Data collection form</u>

<u>نموذج جمع البيانات</u>

This form is used to collect data about formwork labor productivity construction projects in Eastern province, Saudi Arabia. This data to be used in a master thesis research done by Eng. Deya Aldeen Al-Nakdali in King Fahad University for Petroleum and Minerals.

هذا النموذج يستخدم لجمع بيانات إنتاجية العمال في أعمال الشدة الخشبية للمشاريع الإنشائية في المنطقة الشرقية في المملكة العربية السعودية. هذه البينات ستستخدم في بحث رسالة ماجستير في جامعة الملك فهد للبترول والمعادن يحضرها المهندس ضياء الدين النكدلي.

Name …………………..........……………………………………….……… ……… :الاسم

Educational Degree: …………...…………...…………………………:الشهادة العلمية

Company Name:……………………………………………………… :اسم الشركة

Position: ……………………...…....……………………………… :المسمى الوظيفي

Project name:………………….………………...………………….... :اسم المشروع

Location: ……………..........…..…………………….……………………… :الموقع

Contract Price: …………………...………………….....…………………:سعر العقد

Project area: ………………….............…………………………..…… :مساحة المشروع

Note: the type of formwork used must be (**<u>Timber or Plywood</u>**)

ملاحظة: يجب أن تكون الشدة المستخدمة في المشاريع **<u>شدة خشبية</u>** حصراً.

For any clarification or information please fell free to contact.

Email: g201703450@kfupm.edu.sa

Mob: 0504673656

Foundation

القواعد

<u>Type of foundation</u> | **<u>نوع القواعد</u>**:

Isolated foundation | أساسات منفصلة □

Raft foundation | أساسات اللبشة المسلحة أو الحصيرة □

<u>Type of working force</u>: | **<u>نوع العمالة المستخدمة</u>**:

Company direct labor □ | عمالة الشركة/المؤسسة □

Subcontractor □ | مقاول خارجي □

Nationality of workers …………… | جنسية العاملين ....

<table>
<tr><td>Total Quantity of form work (plywood or timber) installed (m^2)</td><td colspan="4"></td><td>إجمالي مساحة الشدة الخشبية المستخدمة (م^2)</td></tr>
<tr><td rowspan="2">Number of working days required to finish the work</td><td>day</td><td>hour</td><td>ساعة</td><td>يوم</td><td rowspan="2">عدد الأيام التي تطلبها إنهاء العمل</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Average Daily working hours</td><td colspan="4"></td><td>متوسط عدد ساعات العمل اليومية</td></tr>
<tr><td rowspan="2">Crew Number</td><td>skilled</td><td>Non-skilled</td><td>عامل</td><td>معلم</td><td rowspan="2">عدد الطاقم</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Depth of foundations

The distance between the street level and the bottom of the foundation</td><td colspan="4"></td><td>عمق التأسيس

المسافة بين مستوى الشارع وأسفل القواعد</td></tr>
<tr><td>Foundation depth</td><td colspan="4"></td><td>عمق القاعدة</td></tr>
<tr><td>Average temperature during the work</td><td colspan="4"></td><td>متوسط درجة الحرارة خلال فترة العمل</td></tr>
</table>

Are there any reasons that cased stopping the work or delay? Pleas mention.

هل هاك أي أسباب أدت لتوقف العمل أو تأخيره؟ الرجاء ذكر هذه الأسباب.

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Columns

الأعمدة

<u>Type of working force</u>: **<u>نوع العمالة المستخدمة</u>**:

Company direct labor □ عمالة الشركة/المؤسسة □

Subcontractor □ مقاول خارجي □

Nationality of workers جنسية العاملين ....

<table>
<tr><td>Quantity of form work (plywood or timber) installed (m^2)</td><td colspan="4"></td><td>مساحة الشدة الخشبية المستخدمة (م^2)</td></tr>
<tr><td rowspan="2">Number of working days required to finish the work</td><td>day</td><td>hour</td><td>ساعة</td><td>يوم</td><td rowspan="2">عدد الأيام التي تطلبها إنهاء العمل</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Daily working hours</td><td colspan="4"></td><td>عدد ساعات العمل اليومية</td></tr>
<tr><td rowspan="2">Crew Number</td><td>skilled</td><td>Non-skilled</td><td>عامل</td><td>معلم</td><td rowspan="2">عدد الطاقم</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Hight of pouring</td><td colspan="4"></td><td>ارتفاع الصب
ارتفاع صب العامود طبقا للمخططات</td></tr>
<tr><td>Floor number</td><td colspan="4"></td><td>رقم الدور</td></tr>
<tr><td>Average temperature during the work</td><td colspan="4"></td><td>متوسط درجة الحرارة خلال فترة العمل</td></tr>
</table>

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Slabs

الأسقف

Type of slap: **نوع السقف**:

Solid slab ◻ بلاطة مصمتة

Ripped slab ◻ بلاطة مضلعة

Flat slab ◻ بلاطة مسطحة

Type of working force: **نوع العمالة المستخدمة**:

Company direct labor ◻ ◻ عمالة الشركة/المؤسسة

Subcontractor ◻ ◻ مقاول خارجي

Nationality of workers …………… جنسية العاملين ....

Drop beams: **الجسور الساقطة:**

Exist ◻ ◻ يوجد

Doesn't exist ◻ ◻ لا يوجد

<table>
<tr><td>Quantity of form work (plywood or timber) installed (m^2)</td><td colspan="4"></td><td>مساحة الشدة الخشبية المستخدمة (م^2)</td></tr>
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<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Slab thickness</td><td colspan="4"></td><td>سمك البلاطة</td></tr>
<tr><td>Floor height
the distance between the surface of previous slap and the bottom of the working slab</td><td colspan="4"></td><td>ارتفاع الدور
المسافة بين سطح البلاطة السابقة و أسفل البلاطة التي يتم العمل بها</td></tr>
<tr><td>Floor number</td><td colspan="4"></td><td>رقم الدور</td></tr>
</table>

Average temperature during the work		متوسط درجة الحرارة خلال فترة العمل

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Vitae

Name :Deya AlDeen Nader Al-Nakdali

Nationality :Syrian

Date of Birth :1/1/1995

Email :deyanakdaly@gmail.com

Address :Az Zuhur District, Dammam, 32423

Academic Background :Bachelor of Science in Construction Engineering

Deya is the recipient of a scholarship jointly awarded by the Custodian of the Two Holy Mosques University program to help Syrian students, and Imam Abdulrahman Bin Faisal University. From that scholarship, he earned a bachelor's degree in Construction Engineering with a focus on construction engineering management, with a distinguished GPA of 4.65 out of 5.0. During his undergraduate studies, Deya developed a robust knowledge of structural engineering, especially with regards to reinforced concrete. Besides manual design techniques, Deya has worked with various computer-aided programs, such as SAP, SAFE, ETABS, Primavera, and MS Projects. To consolidate his knowledge, Deya interned for three months with the Masah Specialized Construction Co. at Dr. Soliman Al-Habib Hospital-Al Khobar project, one of the largest projects in the Eastern Province of Saudi Arabia at that time. Professionally, Deya has worked as a Projects Engineer at Addamegh for Maintenance and Contracting Company on several private projects, where he prepared cost and schedule estimations, solved invoicing disputes with clients, and directly supervised construction work. At that time, Deya was enrolled in the Construction and Engineering Management graduate program at KFUPM as a part-time student, enhancing his scientific knowledge along with his work experience, and maintaining a 3.75 out of 4.0 CGPA.

His research interests include the application of artificial neural networks in construction, labor productivity, development of baseline standards for construction activities, and multi-criteria decision making. Outside of academia, Deya is deeply committed to social activism and humanitarian work. He was a volunteer with the East Volunteers Team during multiple events and has taken the initiative to tutor students on topics such as cost estimation and planning.